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A SIMULATION STUDY COMPARING
MULTI-LEVEL MAINTENANCE CONCEPTS FOR
THE F-16C/D DUAL MODE TRANSMITTER

THESIS

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THESIS

Presented to the Faculty of the School of Logistics
of the Air Force Institute of Technology
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Master of Science in Systems Management

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Abstract

This thesis provides a methodology for the analysis and comparison of various maintenance practices for the F-16C/D Dual Mode Transmitter. The primary goal of this thesis is the determination of whether a reduction from three to two levels of maintenance is viable. The measure of effectiveness selected to compare each maintenance alternative is the number of available spares corresponding to that level of maintenance. Computer simulation is the chosen method to determine this availability.

A SLAM II simulation model was developed to model the failure of the Dual Mode Transmitter and its repair at all three levels of maintenance. The validated model was then subjected to various sensitivity analyses to see which areas were most sensitive. A final analysis was done to compare three versus two levels of maintenance for peacetime flying requirements, for a 30 day wartime flying surge, and for a sustained conflict.

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Chapter I. Introduction

General Issue

Major weapon System Program Offices (SPOs) and the Major Command headquarters are heavily involved with the problem of trying to increase system efficiency for their particular weapon system while trying to maintain or, possibly, reduce expenses. This effort is difficult at best. One area of possible application involves a change of maintenance philosophy for particular components, such as a change from three levels of maintenance to two levels of maintenance for the repair of these components. A typical maintenance philosophy includes three levels of maintenance:

1) flight line removal of the Line Replaceable Unit (LRU),
2) intermediate (base) level limited repair of the LRU by the removal and replacement of sub-components, or Shop Replaceable Units (SRUs), and
3) the depot level repair of SRUs and LRUs. (15:191)

A more detailed explanation of the three maintenance levels is provided in Chapter II.

If an LRU is a low failure item, it may not be cost effective to maintain the equipment and expertise at each

base to repair this item. In such circumstances, a two-level maintenance concept may be employed with the flight line removal of the LRU and the depot repair. This action results in the improvement of system effectiveness by reducing the number of system elements (maintenance levels and their associated equipment) and, at the same time, reduces the cost to maintain the system because of the reduction of these same elements.

A problem associated with a proposed change in levels of maintenance is that the effect on operational capability is not readily known. The elimination of intermediate level maintenance for a particular LRU may lengthen the repair cycle enough that shortages occur and planes are grounded until spares can arrive. This occurrence makes the proposal unacceptable. The purchase of additional spares to meet this demand may keep the proposal from being cost effective. This scenario is only one of numerous possibilities.

Problem Statement

HQ TAC/LGMA-1 asked that a study be performed to compare the effectiveness of two versus three levels of maintenance on the F-16C/D Dual Mode Transmitter (DMT) (9 and 21). The maintenance of the DMT has long been an item of concern for F-16 program management because of the high

cost and high failure rate of one particular subassembly to the DMT, the pressure vessel.

> The maintenance concept for the [F-16C/D AN/APG-68] radar has been established as the classical 3-level concept, but due to the unusual construction of the DMT and the high failure rate of the pressure vessel, it was desirable to examine other maintenance concepts for that one LRU [Line Replaceable Unit]. (8:1)

A cost-effectiveness study was previously done comparing two versus three levels of maintenance on the DMT (8) which compared the long term spares cost for each of several maintenance alternatives. The study did not address such issues as the capability of the system to handle the proposed change in maintenance philosophy and other additional costs and benefits. The study concluded that there was no significant difference between the proposed alternatives, based on long term spares investment, and that "factors other than long term spares costs must be examined to determine which maintenance concept is most desirable" (8:13). This research study will address some of these other factors in hopes of better determining an optimal maintenance philosophy for the F-16C/D Dual Mode Transmitter.

The primary concern of operational personnel is maintaining the capability to fly aircraft. A shortage of spare parts to repair an aircraft, as will be more likely with certain maintenance philosophies, will keep the

aircraft from flying. This is a major concern. If the system is capable of adjusting to two levels of maintenance then these additional questions are raised:

What is the difference in spares availability between the two maintenance concepts?

What changes in manpower and equipment requirements result at intermediate and depot levels of maintenance with the change in philosophy?

Is there a modification to the current three-level maintenance structure that would derive greater benefit than either the three-level or two-level concept?

While beneficial, these questions cannot be answered in their entirety without actual implementation. These questions can be answered fairly confidently, however, by modeling the operation of the system. Once a valid model is obtained which adequately represents system operation, then modifications can be applied to the model and outputs measured to determine the approximate system response to the given modifications. The purpose for this study is to provide such a model, as described below.

Research Objective

The primary objective of this research effort is to provide a valid model of the three-level maintenance and supply system of the F-16C/D Dual Mode Transmitter (DMT). With the model of this system developed, the system operation of the F-16C/D DMT will be examined to identify problems areas affecting DMT spares availability and

unnecessary costs. Modifications to the system will be proposed and analyzed to try to improve the availability of spares. The option of changing to a two-level maintenance concept will be considered. This model will also be constructed such that system parameters for any major LRU on the F-16C/D aircraft can be input to the model for similar analysis.

Research Questions

1. What is the best method/model to evaluate the Dual Mode Transmitter system for the evaluation of spares availability?

2. Does this method/model measure what it claims to measure?

3. Can this method/model be generalized to other components within the F-16C/D?

4. What modifications to the three-level maintenance structure are currently proposed to improve the availability of spares for the DMT?

5. What other aspects of three-level maintenance on the DMT most greatly affect spares availability of the DMT and can they be controlled/modified?

6. Is the reduction to two levels of maintenance for the F-16C/D DMT with current levels of spares and equipment viable?

Overview

This thesis is divided into five chapters. This chapter identifies the general background of the F-16C/D Dual Mode Transmitter and establishes this study's objectives. Chapter II provides specific background

information, definitions, and a review of pertinent literature to better comprehend the problem for a system's analysis. Chapter III provides the procedure (or methodology) by which the problem will be addressed. The methodology in Chapter III is performed with the analysis and interpretation of results provided in Chapter IV. Finally, Chapter V gives a summary of the research findings and gives recommendations for further study.

Chapter II. Literature Review

Introduction

This chapter is organized into three major sections: a review of two versus three levels of maintenance, background of the Dual Mode Transmitter, and the development of a model of the F-16C/D Dual Mode Transmitter maintenance and supply system.

Two Versus Three Levels of Maintenance

Background. The three levels of maintenance mentioned in Chapter I refer to the three most commonly used levels of maintenance: organizational, intermediate, and depot (15:191). Two levels of maintenance refer to the organizational and depot levels of maintenance, (excluding the intermediate level).

> Organizational maintenance encompasses tasks performed by the using organization on its own equipment. This maintenance consists of functions and repairs within the capabilities of authorized personnel, skills, tools and test equipment. Organizational-level personnel are generally occupied with the operation and use of the equipment, and have minimum time available for detailed maintenance or diagnostic check-out. Maintenance at the organizational level is normally restricted to periodic checks of equipment performance, cleaning of equipment, front panel adjustment, and the removal and replacement of some components. Personnel at this level usually do not repair the removed components, but forward them to the intermediate level. (4:91,93)

> [Intermediate-level maintenance] is limited to the repair of end items or unserviceable assemblies in support of using organizations on a return-to-user

basis. . . . At this level, end items may be repaired by replacement of major modules or assemblies. (4:93)

> The depot constitutes the highest level of maintenance, and provides support for maintenance tasks above and beyond the capabilities provided at the intermediate level. The depot level of maintenance provides facilities for completely overhauling and rebuilding equipment as well as the performance of highly complex maintenance actions. (4:93,94)

In past years the Air Force traditionally operated with a three-level maintenance concept. The three-level concept has served the Air Force well in that many of the failures were easily remedied at the base level, resulting in a very short maintenance cycle before the failed components were put back in service. This is a great benefit to the operational units who depend on their own abilities to "turn aircraft around" -- to get the aircraft back flying after a critical failure. If a two-level maintenance concept were employed, the assets would be tied up in transit to and from the depot repair facility, and the base would have very little control over these assets.

With technology improvements come additional considerations. Many high technology components require extremely expensive test equipment for diagnostics and repair. Some of these components have had large reliability improvements such that this expensive test equipment is underutilized. Additionally, the test procedures can require highly skilled technicians to perform the

diagnostics. Consequently, base repair shops have had to maintain expensive equipment and high-level training which is frequently underutilized. It is obvious that three-level maintenance is not always the best answer.

Repair Level Analysis. To properly determine what level of repair is most appropriate, a Repair Level Analysis (RLA) is performed in accordance with AFLC/AFSC Pamphlet 800-4, "Repair Level Analysis (RLA) Procedures." "The RLA process provides an economic basis for determining where repairs are to take place" (5:2). The options are intermediate level repair, depot level repair, or to throw the component away. Considering that RLA is to be done throughout the life of a program it is quite conceivable to change the level of repair for a particular component. (5:2)

The F-16 System Program Office (SPO) is seriously considering a major reduction in the number of LRUs hosted on the F-16C/D Avionics Intermediate Shop (AIS) changing many of the LRUs to two-level maintenance. A simplification of test procedures and the elimination of unnecessary test equipment will benefit both the strict peacetime scenario and the deployment. The method of obtaining this reduction of AIS activity includes increasing the reliability of selected LRUs and the reduction of Cannot Duplicates (CNDs) (6:7). Some of the benefits of these two actions are, respectively, to decrease the number of failures and to

cause fewer false removals of LRUs from the aircraft. Decreasing the number of failures lessens the utilization of the intermediate level of maintenance and makes two-level maintenance more favorable. Fewer false removals from the aircraft also lowers the workload/utilization on the AIS. The proposed F-16C/D selection criteria for eliminating intermediate level repair for particular LRUs are as follows:

- less than 5% of load on assigned station
- little or no repair possible at I[ntermediate]-level
- sole user of a high dollar station asset
- reasonable/attainable increase in reliability would predicate a two-level decision
- LRU costs less than assigned ITA [Intermediate Test Adapter]
- General Dynamics original recommendation was two-level (7:54)

<u>Dual Mode Transmitter</u>

<u>Background</u>. The Dual Mode Transmitter (DMT) is one of five Line Replaceable Units (LRUs) in the F-16C/D radar (the AN/APG-68 radar). The other four LRUs are the Radar Antenna, the Modular Low Power Radio Frequency unit (or MLPRF), the Programmable Signal Processor (or PSP), and the Radar Rack Assembly. The primary function of the DMT "is to provide a pulsed, high-power radio frequency signal to the antenna LRU" (2:II-2). The principal component within the DMT is the Pressure Vessel Assembly (PVA), a high powered traveling wave tube. The PVA is also the primary cause of

failure for the DMT. The F-16C/D Centralized Data System (CDS) lists the DMT as having a cumulative Mean Time Between Failure (MTBF) for all United States Air Force aircraft of 181 hours and ranks it as the second worst LRU in the radar. (See Table 1).

Table 1.
Mean Times Between Failure (MTBF)
for the F-16C/D Radar LRUs
(in hours)

Nomenclature	Work Unit Code	MTBF
PSP	74AQ0	127
DMT	74AP0	181
Modular LPRF	74AN0	195
Radar Antenna	74AM0	554
Rack Assembly	74AS0	75,087

A Mean Time Between Failure (MTBF) of 181 hours for the DMT is well above its initially projected MTBF of 100 hours (10). Even so, CDS ranks the DMT as the 5th worst component in the F-16C/D Fire Control System (in terms of MTBF) and as the 16th worst in the entire aircraft. The DMT receives much attention in the Program Office. Potential reliability improvements to the system are minimal in that no new technology has emerged in the area of traveling wave tubes. No reliability improvement modifications are currently planned for the DMT. (Note research question number four.)

The trend of the MTBF for the DMT is fairly stable at 181 hours.

The DMT is currently maintained under a three-level maintenance concept. Upon failure of the DMT at the organizational level (on the aircraft), the LRU is sent to the base level Avionics Intermediate Shop (AIS), the intermediate level of repair. Upon reaching the AIS, the DMT failure is isolated approximately 75 percent of the time (8, 2:I-1, and 3) to the failure of the Pressure Vessel Assembly (PVA), a Shop Replaceable Unit (SRU) within the DMT. The PVA is a highly technical item and "is not authorized for repair at the intermediate level" (2:I-1). Since the PVA is such a large part of the DMT it is placed back in the DMT upon failure, and the DMT is shipped (Not Repairable This Station, or NRTS) to the depot repair facility as a complete LRU. The NRTS rate directly corresponds with the identification of a PVA failure.

Request for Study. As stated in Chapter I, HQ TAC/LGMA-1 asked that a study be performed to compare two and three levels of maintenance on the DMT (9 and 21). One of the more common reasons for trying to eliminate an intermediate level of maintenance is that the LRU is so reliable that it is not cost effective to maintain the equipment and expertise at each base level repair facility for such an infrequent occurrence. The situation with the

Dual Mode Transmitter (DMT) is different. With a 75% NRTS rate, 75% of the time that a DMT is processed through the AIS it is repackaged and sent to the depot for repair. If the AIS were bypassed and the DMTs were shipped directly from the flight line (organizational level) to the depot, then the personnel and equipment requirement at the AIS could be reduced. On the other hand, shipping those assets directly to the depot eliminates the possibility of the base level repair retaining the 25% that otherwise would not have been shipped to the depot. This will tie up more assets in repair at a given time, will cause longer average repair times for the DMTs, and may prompt the purchase of additional DMTs to avoid shortages.

The DMT would seem to meet the previously stated requirement for being considered as a candidate for two-level maintenance since there is "little or no repair possible at I-level" (7:54); however, the F-16 studies referenced do not list the DMT as one of the candidates for removal from the AIS, but do recommend a simplification of testing procedures by the elimination of the phase noise test on the AIS (7:57).

Both HQ TAC and the F-16 SPO are very much interested in the system response to a change in maintenance philosophy for the F-16C/D DMT. Other studies on the subject have been

done, but both organizations desire additional examination, especially from a different perspective/methodology.

Development of the System Model

Cost Models versus Simulation. Chapter I alluded to a cost-effectiveness study performed on the DMT for the consideration of a two-level maintenance structure versus the status quo three-level. The problem with the study, as was stated in its own conclusion, is that additional factors "must be examined to determine which maintenance concept is most desirable" (8:13 and 17). The F-16C/D maintenance and supply system is a dynamic system, meaning that many of the inputs to the system are variable and perhaps interrelated. With a dynamic system it is difficult, if not impossible, to determine analytically the extent to which changing a particular aspect of the system will affect another part (19:11). A favorable alternative to the analytical cost model is the systems approach.

> Systems analysis, that is, analysis to suggest a course of action by systematically examining the costs, effectiveness and risks of alternative policies or strategies -- and designing additional ones if those examined are found wanting - represent an approach to, or way of looking at, complex problems of choice under uncertainty. (18:1)

Simulation is a common form of systems analysis.

Simulation is "the process of conducting experiments on a model of a system in lieu of either (1) direct

experimentation with the system itself, or (2) direct analytical solution of some problem associated with the system" (13:1). As was mentioned earlier, the direct analysis of the system may not be effective, at least not with a general cost-effectiveness model, due to the system's complexity. A direct experimentation with the F-16C/D maintenance cycle for the DMT is also unacceptable due to the tremendous uncertainty and cost involved. Simulation proves to be a good analytical tool under both circumstances. Simulation is selected as the method to evaluate the maintenance and supply system of the Dual Mode Transmitter. This selection directly corresponds to the first research question posed in Chapter I: "What is the best method/model to evaluate the Dual Mode Transmitter system?"

Simulation Language. A number of possibilities are available for the selection of a programming language. General-purpose languages, such as FORTRAN and BASIC, are sometimes utilized for simulation models. This is especially true of FORTRAN. Specific languages, however, have been developed for the purpose of simplifying the simulation process by providing a "natural framework" (12:115) for developing and revising the model. Some of the primary benefits of using a simulation language over a general-purpose language is that the language more closely

resembles the system being modeled; for example, a queueing system can be represented in a simulation language by any of a number of variations of the QUEUE statement. The representation of a queue in FORTRAN is much more complicated.

The selection of a particular simulation language is still broad considering the number of possibilities. Law and Kelton recommend narrowing the selection to GASP, SIMSCRIPT, GPSS, and SLAM; GASP, SIMSCRIPT, and GPSS are noted as being "probably the most widely used simulation languages in the United States", and SLAM "is likely to be the successor to GASP" (12:115).

Any of these four languages would probably serve well in modeling the F-16 maintenance and supply system. The selection, however, is made to use SLAM II, a FORTRAN based simulation language. SLAM II is quite effective in modeling flight operations and maintenance/supply systems. SLAM II has recently been utilized in modeling such Air Force aircraft maintenance and supply systems as the B-1B, the C-17, and a concurrent study on the F-16, to name a few. These prior studies and the availability of SLAM II on accessible computer facilities make SLAM II a good choice for selection of a simulation language.

The Simulation Process. Simulation, as with all computer programming, is an art. The potential applications

for simulation models are as numerous and distinct as the systems in the universe. The methods for representing these systems in models rely on the programmer's skills and ingenuity. As such, no rigid guideline can be offered to dictate the appearance of the model. Conversely, the process for obtaining the desired output of the simulation model should be established to insure that the model is reliable and repeatable, regardless of the programming technique. The scientific method of experimentation is a sound means of establishing such a reliable and repeatable process. Very basically, the scientific approach is a four-step process: problem formulation, design of the experiment, execution of the experiment, and analysis. Specific renditions of this approach have been developed to aid in the experimentation process within particular disciplines. Mize and Cox provide such a methodology for the development of simulations which they refer to as a "systematic approach to the study of systems via the methods of simulation" (13:139). This approach is shown in Figure 1.

Chapter III, entitled Methodology, provides the specific details to be followed in the development, execution and analysis of this simulation for the DMT. The Mize and Cox approach follows this methodology, provides a number of specifics to insure that the process is reliable

Problem Formulation
- Purpose of the Study
- System Description
- Recognition of Assumptions

The Design of Simulation Experiments
- Formulation of a Mathematical Model
- Data for Simulation Experiments
- Sampling Considerations
- Model Validation

Constructing the Computer Model
- Starting Conditions and Equilibrium
- Time-flow Mechanism
- Process Generators
- Parameter Changes and Alternative Decision Rules
- Record Keeping and Generation of Statistics
- Organizing the Computer Model
- Computer Model Validation

The Analysis of Simulation Data
- Statistical Tests
- Interpretation of Results

Figure 1. A Systematic Approach to the Study of Systems via the Methods of Simulation (13:139)

and repeatable, and provides the basic outline and guidance for Chapter III.

Chapter III. Methodology

Introduction

The development of a simulation model for the maintenance of the Dual Mode Transmitter (DMT) will be structured around the procedures described in Chapter III. A similar procedure provides the outline for this chapter.

Problem Formulation

Purpose for Study. The problem statement, purpose of the study, and the system description were given in Chapters I and II. In summary, a study was requested on the maintenance and supply system for the F-16C/D Dual Mode Transmitter to see if a two-level maintenance approach for the DMT is feasible. In response, a simulation analysis will be performed on the system to address the current status of the DMT maintenance and supply system and to investigate possible modifications to the system. The strength of each potential modification will be based on the number of available spares at each location as compared to those of the alternative modifications and the status quo.

System Description. All operational F-16C/D currently in the United States Air Force inventory will be included in this analysis. The system includes 643 F-16C/D aircraft,

which are spread across 5 major commands and 15 bases. The distribution of aircraft by base and the corresponding flight hours and Mean Times Between Failure (MTBF) are given in Table 2. All quantities are based on an "as of" date of 1 Mar 1989.

Table 2.
Distribution of Aircraft
and Flying Hours, F-16C/D

Base	Number of Aircraft	Cumulative Flight Hours	MTBF
Bentwaters	12	837	---
Edwards	11	1,190	170
Eglin	7	3,262	171
Hahn	77	55,847	236
Kunsan	51	12,731	78
Luke AFB	59	42,308	131
Luke AFR	26	7,477	356
Macdill	56	4,795	319
Misawa	52	24,151	160
Nellis	36	6,242	161
Osan	22	541	135
Ramstein	51	40,753	148
Shaw	77	100,602	183
Spangdalem	36	12,642	258
Torrejon	70	15,015	234
USAF	643	328,393	181

The initial system is based on a three-level maintenance structure for the F-16C/D Dual Mode Transmitter (DMT). Each base is assumed to have its own organizational and intermediate levels of maintenance. The Westinghouse

plant in Hunt Valley, Maryland is the common depot facility for all DMT.

Diagnostic test times at the intermediate level are assumed to be a standard two hours per test. An additional two hour test is required following any repair or modification to the LRU.

Failure rates are unique to each base and are given in Table 2 (in terms of Mean Time Between Failure, MTBF). The demand of a particular unit from supply is based on the Mean Time Between Demand (MTBD), not the MTBF. The MTBD is equal to the total flight hours for a given period divided by the total number of maintenance actions, whereas the MTBF is equal to the flying hours divided by the number of inherent failures. The determination of the MTBD can be derived as follows:

$$\text{MTBD} = \frac{\text{flight hours}}{\text{total maintenance actions}}$$

$$\text{MTBF} = \frac{\text{flight hours}}{\text{number of inherent failures}}$$

$$\text{MTBD} = \text{MTBF} * \frac{\text{number of inherent failures}}{\text{total maintenance actions}}$$

$$\text{MTBD} = \text{MTBF} * \left[1 - \frac{\text{number of non-failures}}{\text{total maintenance actions}}\right]$$

Note that failures other than inherent failures are negligible for the DMT. The number of non-failures divided

by the total maintenance actions is very closely approximated by the Bench Checked Serviceable (BCS) rate. (A BCS action occurs when an LRU is processed across the AIS and no failures are found.) As a result, the MTBD for the DMT for the DMT can be derived as follows:

MTBD = MTBF * (1-BCS rate)

The F-16C/D sortie length has an average of 1.7 hours. Sortie length was assumed to be normally distributed with a standard deviation of 0.2 hours.

The number of available spare DMTs appears favorable; in addition to the 643 DMT which reside in the aircraft at a given time, another 693 are available as replacement units. Assuming this number to be excessive, a simplification of the model is made in that the number of spares is set to 643, or one additional LRU for every aircraft. The remaining 50 LRUs are to be considered surplus/reserve. In actuality, 351 spares are required for War Readiness Spares Kits (WRSK) (1). A requirement also stands for having approximately 120 spares on hand at the bases as replacement assets (10). The number of spares in the WRSK and those others on hand will not affect the model but will be a factor in the final analysis.

The repair rates, bench checked serviceable (BCS) rates, and Not-Repairable-This-Station (NRTS) rates differed

somewhat, depending on the source of the information. A determination was made to use data extracted from the first quarter 1989 Retest-okay Analysis and Corrective Action Team (RACAT) minutes. RACAT is a noteworthy maintenance analysis team that utilizes CDS data. The values selected for use in this study are a 12.5% repairable rate, a 15% BCS rate, and a 72.5% NRTS rate. There are no reported condemnations of the DMT.

Pipeline. All depot maintenance on the DMT is performed by Westinghouse in Hunt Valley, Maryland; the United States Air Force does not have organic repair capability on the DMT. Once a DMT is declared Not Repairable This Station (NRTS) at the intermediate level, the DMT is shipped to Ogden ALC and is then disbursed to Westinghouse for repair. Upon completion of repair the LRU is shipped back to Ogden to await further disbursement instructions. This cycle from the base to Ogden to Westinghouse and then back to Ogden requires 98 days on average. From Ogden back to the base takes another eight days. This cycle time does not account for any variations in the system such as CONUS versus overseas shipments and depot backlogs. Nonetheless, it will have to suffice for representation of the maintenance pipeline.

More detail is required in the model, however, for the actual depot repair of the DMT. The current utilization of

the depot is required to project if a change to the system will cause a backlog at the depot. The number of depot test stations is known, but this appears to have little correlation to the number of LRUs actually processed. Very few or very many iterations could be made across a test station with a single LRU, depending on the nature of the repair. Two constraints that are more binding on the system operation are the average depot repair flow time of 10 days and Westinghouse's ability to process roughly 45 DMTs per month on two shifts (11). For these constraints the number of servers will have to be iteratively determined during model development. This number of servers will not be a literal representation but will be a baseline figure that can be adjusted by various proportions to represent corresponding adjustments to depot utilization. Westinghouse, for example, is anxious to expand to three shifts, dependent on the workload (11). This would be easily modeled.

Assumptions. Many of the assumptions will be addressed with each applicable section of this methodology, but a few are now germane as they apply to the initial development of the model. For this model, the following apply:

- All currently operating, United States owned, F-16C/D aircraft will be included.
- Current operating conditions for the aircraft and the DMT will be used throughout the simulated lifetime.

- The model will be based on a peacetime scenario.

Even though this study is not intended to represent all future possibilities for the F-16C/D and the DMT, it is a goal for the model to be versatile; the critical parameters of the system should be easily modified to reflect different operating conditions/contingencies. This inherent versatility will also simplify the generalization of the model to other components. (Note research question number three.)

The Design of Simulation Experiments

Formulation of a Mathematical Model. The major product of this study will be the development of a computer simulation model for the DMT maintenance and supply system. Having a valid computer model, however, is totally dependent on the development of a mathematical model that reflects the operation of the system to an adequate degree. (Perfect representation is not possible.)

Understanding the System. A full understanding of system operation is first required in the formulation of a mathematical model. This understanding is obtainable through current literature, from points of contact at the F-16 SPO and various F-16 maintenance units, and from the DMT Item Management Specialist at Ogden ALC. While

countless aspects of system operation could be analyzed, the focus of this model will be limited to the parameters of the F-16C/D system which most greatly affect the availability of spares.

The presumed most critical aspects of the mathematical model are the Mean Time Between Failure (MTBF) of the DMT, the Mean Time Between Demand (MTBD), the number of aircraft assigned to each base (with the respective scheduled flying hours), the Mean Time To Repair (MTTR) at each maintenance level, and the total number of spares in the system. The MTBD, MTBF, and MTTR are not likely to change much over time, but the number of available spares might change greatly due to a minor change in any of the three. The number of available spares must be carefully examined for any modifications to the system. Sensitivity analysis will be fully addressed later in this chapter.

Availability of Spares. The availability of spares can be explained using three simple measures: reliability, quantity of spares, and repair time. Concerning the reliability of the LRU, if the LRU doesn't fail then spares are not needed. A high failure rate corresponds to a need for a high number of spares. Secondly, the actual number of spares in the system is directly related to the number available. Finally, if the length of time required to repair the LRU is negligible,

then the LRU can be immediately put back into an aircraft, again minimizing the need for spares. A more thorough description of these measures follows.

As stated in Chapter II, no reliability improvements are currently planned for the DMT. (Note Research Question number four). The purchase of additional spares is an option, if needed. This would increase the number of spares available. Conversely, if a surplus of spares is discovered the option of selling these surplus spares becomes viable.

The final factor affecting spares availability is the time to repair. The time to repair is dependent on factors such as the NRTS rate, the Bench Checked Serviceable (BCS or Cannot Duplicate, CND) rate, the actual diagnostic time requirements at the intermediate and depot levels, and the transit times to and from the depot. Various sources give the DMT NRTS rate values ranging from 72.5 to 85 percent. The F-16 Centralized Data System (CDS) lists the DMT at 72.5 percent NRTS. This value will be used. Quoted values for the BCS rate ranged from "negligible" to a high value of 15 percent, given by CDS. The CDS value will again be used. CDS shows these rates to be fairly stable.

The actual time for diagnostics raises some additional problems. Both the intermediate and the depot levels of maintenance have their standard test station times. These times are valid unless there is a backlog of LRUs waiting to

be tested on the test station, thus lengthening the diagnostic process. This circumstance happens quite infrequently, at least at the AIS (20). In general, the elimination of intermediate level maintenance would shorten the total repair time (pipeline time) for those LRUs which would have been sent to the depot anyway and would lengthen the pipeline time for all others. The net result is to be determined.

Data for the Simulation Experiments. The F-16 Centralized Data System (CDS), G333, is the primary source of reliability and maintainability information for this study. CDS is an on-line maintenance data collection system which can be queried to obtain historical reliability and maintainability information on all major components on the F-16 (including the Dual Mode Transmitter). Much of the information required for the simulation model is not specific maintenance data (for example, the quantity of spares in the system) and is not available in CDS or any other maintenance data collection system. This information will be obtained through other sources as necessary. ASD/YPLI (the F-16 System Program Office) and OO-ALC/MMA (F-16 System Program Management) will be primary points of contact for this information. Finally, the cost-effectiveness study on the DMT (8) addressed in Chapter II

contains considerable background information and will be utilized.

<u>Sampling Considerations</u>. The F-16 Centralized Data System is unique in that it can be easily queried to get the great majority of the reliability, maintainability, and supportability data for all major avionics components within the F-16. Reliability data, for example, can be provided in terms of part number, serial number or work unit code and can be generalized to aircraft level, base, wing, numbered Air Force, command, or the entire Air Force. For the purpose of this study, the data in CDS is exhaustive and will be considered to be the population.

<u>The Bathtub Curve</u>. All historical failure data for the DMT will be utilized in determining the appropriate failure distributions for the pending model. Failure data will be summarized by month for each base in order to generalize for use in the model. The F-16C/D has been flying for over four years and has over 300,000 flying hours. Therefore, the DMT would presumably be operating in the constant failure portion of the reliability life cycle "bathtub" curve, meaning that it has matured past the point of "infant mortality" and has not begun to "wear out." (Note Figure 2.)

<u>Determining the Distribution of Input Data</u>. The constant failure portion of the bathtub curve typically

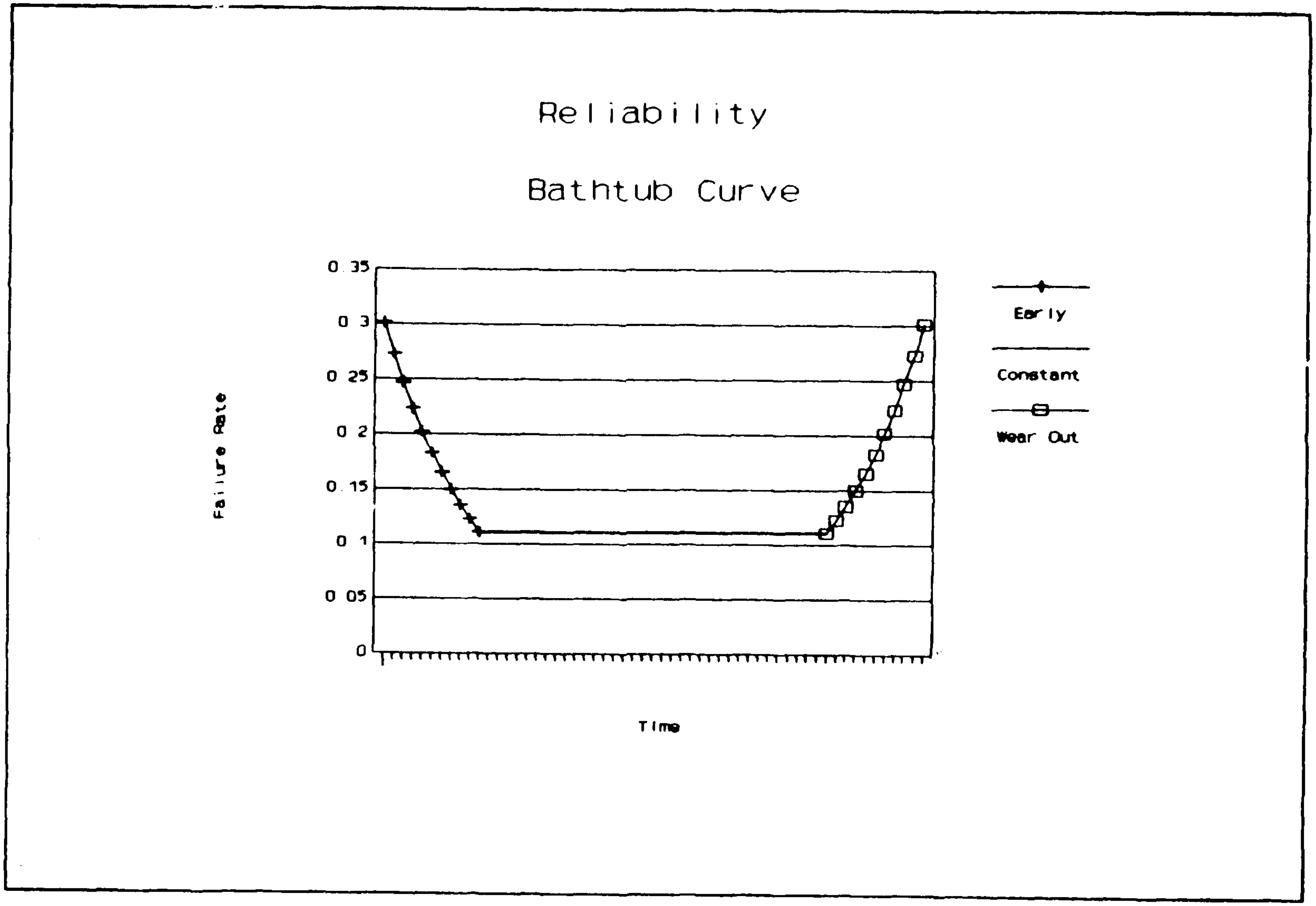

Figure 2. Reliability Bathtub Curve

corresponds to an exponential distribution of the data. This assumption can be tested using a goodness-of-fit test such as Chi-Square or Kolmogorov-Smirnov (KS). A goodness-of-fit test may be required to test a specific distribution hypothesis for each base. A more desireable approach is to categorize bases with common failure characteristics. This grouping will simplify model development and will enhance the understanding of system operation. Potential categories for failure distributions will be based on specific blocks of aircraft (showing approximate age of the aircraft), months of actual operation of the F-16C/D at the particular bases (showing possible level of technician expertise and system maturity), flying hours of operation (another test of system maturity -- not all bases have the same number of wings), geographic areas, and major commands.

Deterrents. Severe random or seasonal fluctuations in failures can deter visual or analytical determination of a failure distribution. Positive or negative reliability growth can also cause some confusion because the question arises as to whether the system will continue with the previous trend or level off at a pending equilibrium point. The possible complications are numerous, if not infinite. Methods for dealing with the complications will be reserved until the actual data is analyzed in Chapter IV.

Model Validation. The simulation model is not intended to be and is not capable of being an exact replication of the DMT maintenance system but is expected to adequately represent the system such that inferences can be made. Numerous techniques are available to test simulation models for such validity, although not all techniques are appropriate for all simulation models. Four of the validation techniques to be used for this model are (1) comparison to other models, (2) face validity, (3) internal validity, and (4) reproduction of past data.

Validation by comparison to other models will occur automatically because the model will be based on current models which have already been validated. Face validity means the model will appear logical to persons who are familiar with the system being modeled. Many local experts on the F-16, including persons at the F-16 SPO, are available for counsel and will be relied upon. The model will be tested for internal validity to examine the variability in the output from several replications. Finally, many characteristics of the F-16C/D maintenance and supply system are known such that the operation of the model can be compared to the actual operation of the system.

Constructing the Computer Model

Starting Conditions and Equilibrium. At the initial start-up time for the simulation, the system will be operating in a state that is less than optimal, thus giving inconsistent output information concerning the state of the system (the number of available spares). An initial warm-up period is required to allow the system time to overcome this transient state such that it exhibits steady-state behavior and the number of spares stabilizes around some value. An extremely beneficial output of the simulation is a plot of the number of available spares versus time. This plot contrasts the steady-state and transient behavior and helps to determine the completion of this transient state.

With computer time being at a premium, various methods have been developed for determining the shortest time period corresponding to the end of the transient state. Computer time is not expected to be critical for this study, so the beginning of steady-state will be conservatively determined from the plot.

Run Length. The end of the above defined transient state does not normally result in a perfect steady-state. The transient state usually has a residual effect on the system with cycles of high and low output behavior. Over time, however, these cycles should dampen to where the variation of values around the steady-state value is

minimal. Lower variability about the steady-state value means that a more precise value can be determined from the simulation.

Even though computer time is not critical for this study, it is not possible to run the model long enough to remove all variability and, thereby, increase confidence in the output to one hundred percent. A confidence level should be predetermined, and the model should be run only long enough to obtain this limit.

The batch means method is to be employed to determine the shortest acceptable length for a simulation run. The number of spares available at each location is to be divided into equal time intervals. A trial interval size of one year (8760 hours) is selected. The model is to be run for 16 years to generate 16 intervals. A one-way Analysis of Variance (ANOVA) is proposed to do a multiple comparison of the means of the various batches. The ANOVA will be performed on each half of the total number of intervals, i.e., the lower eight interval means are averaged and compared against the average of the upper eight interval means. An appropriate F-Statistic will be determined for the corresponding degrees of freedom and an alpha value of 0.10. The hypothesis that the means are equal will be rejected if the F-Statistic generated from the ANOVA exceeds the test statistic (14:410).

Assuming that the test does not fail, a time frame smaller than eight years will be considered. Each of the two eight-year intervals will be divided in half, and the means of all four four-year intervals compared in similar fashion. This process will be repeated until the test fails or until the minimum interval length chosen is determined to be acceptable.

Number of Runs. The above process results in a fairly precise number for the availability of spares at the various bases. This number, however, is biased by the random number seed which initialized the process. The simulation model with the above determined run length must now be rerun using other independent random number seeds. These additional runs will produce independent estimates for the numbers of available spares, from which a more accurate estimate can be obtained. Having enough runs can be critical to the accuracy of this estimate. The equation for the number of runs required is as follows:

$$n = \frac{(Z_{\alpha/2})^2 * \sigma^2}{E^2} \qquad (14:131)$$

where
α = the confidence coefficient,
Z = standard normal Z-score,
σ = standard deviation of the population,
E = one-half the confidence interval, and
n = the number of runs required.

The confidence coefficient, α, is set at 0.10 which makes $Z = 1.96$. The population variance is not known but is to be estimated using the sample standard deviation. Assuming there is some variance in the separate sample standard deviations, an average standard deviation will be generated from 30 independent samples. The confidence interval is set at 6 such that $E = 3$.

<u>Time-flow Mechanism</u>. This element is not a problem because of the selection of the simulation language. SLAM II strictly works on the premise of event scheduling (16:393). "The user simply schedules events to occur, and SLAM II causes each event to be processed at the appropriate time in the simulation" (16:339).

<u>Process Generators</u>. As with the time-flow mechanism, SLAM II provides its own function generator for random numbers and statistical distributions. SLAM II allows these functions and other user defined functions to be generated internally from SLAM II functions or from FORTRAN subroutines (16:107).

<u>Sensitivity Analysis</u>. Mize and Cox say, "Whenever we doubt any of our parameter estimates, we should perform a sensitivity analysis, even though the primary purpose of the study is to evaluate alternative decision rules" (13:161). A desireable trait of the model (and the system) is the resultant change in the number of available spares due to a

change in a key system parameter by a given amount. It is often found that a small change in a certain parameter will have a very large effect in system operation while other parameters will have much less effect. This information is invaluable for management decisions such as whether to do a reliability improvement modification to an LRU or to buy additional spares. A sensitivity analysis is also of great benefit in that none of the inputs to the model stem from perfect information; individual input parameters can be varied to observe the system response.

The proposed model will have several parameter estimates which will have some degree of uncertainty associated with them. The Not Repairable This Station (NRTS) rate, for example, is quoted as having values ranging from 72 to 85 percent (3 and 9). Among the many system parameters for which sensitivity analysis is appropriate are the MTBD, length of sortie, number of flying hours, number of depot servers, and the pipeline time for repair. A sensitivity analysis will be performed on these parameters.

One possible approach for analyzing the various sensitivities is to give the approximate change in the system parameter which yields a given change in the number of available spares. This approach allows a comparison across the different sensitivity analyses. This approach will be followed for a given change of plus or minus five

percent in the base number of spares. An exact match to the five percent change is extremely doubtful, but approximate values are all that is necessary. The proposed method for obtaining these approximate values is the plotting of enough points to estimate a trend line through the appropriate range. The points corresponding to the five percent change in spares availability will be read off the graph.

Alternative Decision Rules. The evaluation of alternative decision rules is a major objective of this simulation model. HQ TAC/LGMA-1 asked specifically for the evaluation of a two-level maintenance concept in comparison with the current operation. Other alternatives will be considered based on the critical areas of operation in the system as determined by the sensitivity analyses.

Record Keeping and Generation of Statistics. SLAM II inherently provides a number of methods to acquire statistics on the various elements of the system/model (16:282). Both statistical and pictorial presentations of the data are easily obtained through SLAM II, both in time-based presentations and in histograms. Statistics on all parameters needed for validation and verification and for the sensitivity analyses will be included in the model. Some of the critical parameters to be included are the number of aircraft at each location, the total number of flight hours/sorties for each location, the number of DMT

removals, the corresponding numbers of repairs, NRTS, and BCS, and the lengths of the various queues. The only major confining queue in the system is that at the depot.

Organizing the Computer Model. "Most computer simulation models written in the FORTRAN programming language consist of a main program and several subroutines" (13:163). SLAM II is not unique here; SLAM II also utilizes FORTRAN sub-routines, even though SLAM II is capable of generating most FORTRAN functions. FORTRAN is more efficient than SLAM II in performing certain functions, is well established in simulation techniques, and can, therefore, be used to improve computer system efficiency. The goal of this study, however, is not to develop the most efficient simulation model possible but to build a model that adequately represents the system in question. FORTRAN programming will be used to supplement SLAM II coding only as necessary. As an example, a FORTRAN program will be utilized to redimension SLAM II for the large scale simulation proposed. SLAM II has set dimensions which are adequate for most small to medium size programs, but not acceptable for larger ones. Redimensioning SLAM II through FORTRAN is common.

Computer Model Validation. "A computer model is considered valid if it produces results that would be produced by the real-world system the computer model is

supposed to represent" (13:164). Model validation will, of course, be another large part of this research effort. All areas of the model will have to be examined to see if they work together and if they measure what they claim to measure. Mize and Cox explain that

> In some situations we can validate the performance of a computer simulation model by entering historical data into the model and comparing the simulated results with known results. A goodness-of-fit test might be performed to test whether the simulation model is a reasonably faithful analog of the system. (13:165)

Model validation will actually occur throughout the model development process. Since actual input data will be utilized in every phase of development, realistic (valid) outputs must be obtained before proceeding to subsequent phases.

The Analysis of Simulation Data

Statistical Tests/Interpretation of Results. With the completion of the model development and the necessary runs, a determination needs to be made as to which alternatives/ maintenance concepts are most acceptable. An evaluation of the model operation under peacetime situations may be sufficient to exclude certain options. A two sample t-test may be necessary to distinguish between alternatives. The possibility of a war, though, causes different limits to be placed on the peacetime environment. Adjusting the model

for wartime flying conditions will be considered if deemed necessary.

Summary

This chapter described the methodology for developing a simulation model to represent the maintenance and supply system for the Dual Mode Transmitter. The focus in the development of the model is an analysis of the current three-level maintenance structure with respect to alternative practices, especially that of changing to two levels of maintenance. The measure of effectiveness to be used in analyzing each alternative is the expected number of available spares corresponding to that alternative.

Chapter IV provides discussion on model development and the analysis and results of the comparison of two versus three levels of maintenance.

Chapter IV. Results and Analysis

Introduction

This chapter describes the actual process of developing and running the simulation model. The initial model represents the current three levels of maintenance and is the baseline for all future comparisons. After the basic model was validated the system model was revised to reflect potential modifications to the system itself. The primary modification to the model was the reduction of DMT maintenance levels from three to two. Sensitivity analyses also drove the consideration for other potential modifications. This chapter has three major sections: 1) a description of the actual process of developing the model, 2) the initialization of model parameters, and 3) the execution of the model with modifications and corresponding analyses.

Development of the Basic Model

As Chapter I stated, the primary objective of this research effort was to provide a valid model of the three-level maintenance and supply system of the F-16C/D Dual Mode Transmitter (DMT). By having a valid model for the system it was possible to consider any number of modifications to

the system. An attempt was made to establish all system parameters as current as of 1 March 1989.

Failure Distributions. Initially, the intention was to plot all the failure data for each F-16C/D base individually and to obtain individual distributions for each base. All bases were expected to display exponential failure trends for their DMTs, thus suggesting that a goodness-of-fit test might be appropriate. The failure data for each base was readily available from CDS. A simplification to this process was subsequently recommended such that those bases with similar failure distributions and magnitudes were classified together. The benefit of such classifications is not only the simplification of the modeling process, but also a simplification from the reader's/user's perspective; the model has fewer components and can be more easily understood and modified. These classifications resulted in even more notable benefits, as will be discussed later.

As stated in Chapter III, the possibilities considered for the classification of bases were the specific blocks of aircraft (showing approximate age of the aircraft), the months of actual operation of the F-16C/D at the particular bases (showing possible level of technician expertise and system maturity), flying hours of operation (another test of system maturity -- not all bases have the same number of wings), geographic areas, and major commands. Numerous

graphical comparisons were made until a suitable classification scheme was found. The classification by major command was finally chosen. A graphical display of this classification is shown in Figures 3 through 6. These graphs added considerably to the understanding of the failure distributions for some of the bases. Consider Osan Air Base (Figure 3), for example. Without a comparison of Osan's MTBF performance to that of the other PACAF bases it would be extremely difficult to try to determine an appropriate distribution for the failure data. The trend could be just starting a long climb, or the trend could plummet after its initial operating period, as many of the other bases have done. But when plotted with other bases from the same command and geographical location, it can be stated with some large degree of certainty that the failure trend has just reached a level of equilibrium which is very similar to other bases in PACAF.

Without prior knowledge, it was expected that a higher number of cumulative flight hours at a given base would correspond to a higher Mean Time Between Failure, due to the learning curve at each base. This relationship was found to be false, but is presented in Figure 7 nonetheless as an example of the many comparisons performed. The bases are ranked in order of total flight hours.

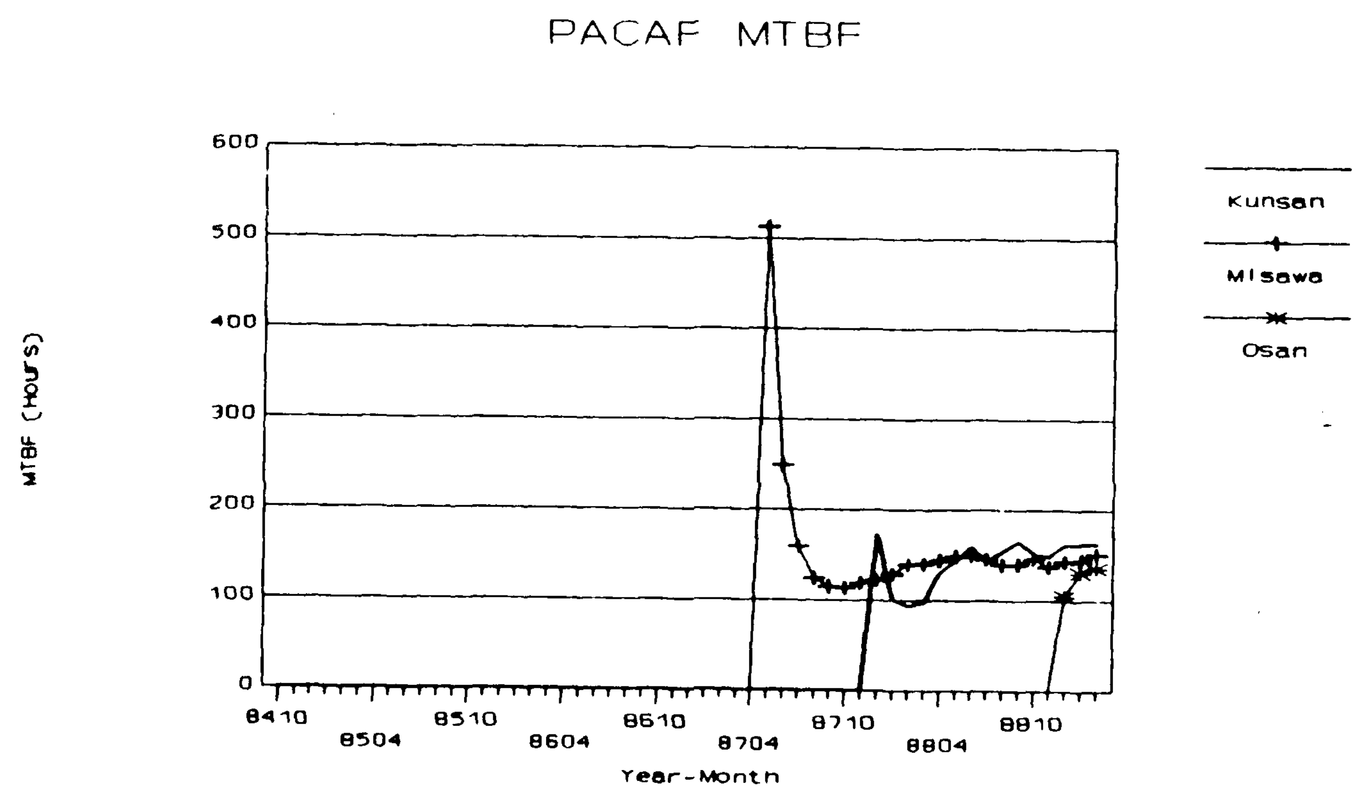

Figure 3. PACAF Failure Trend

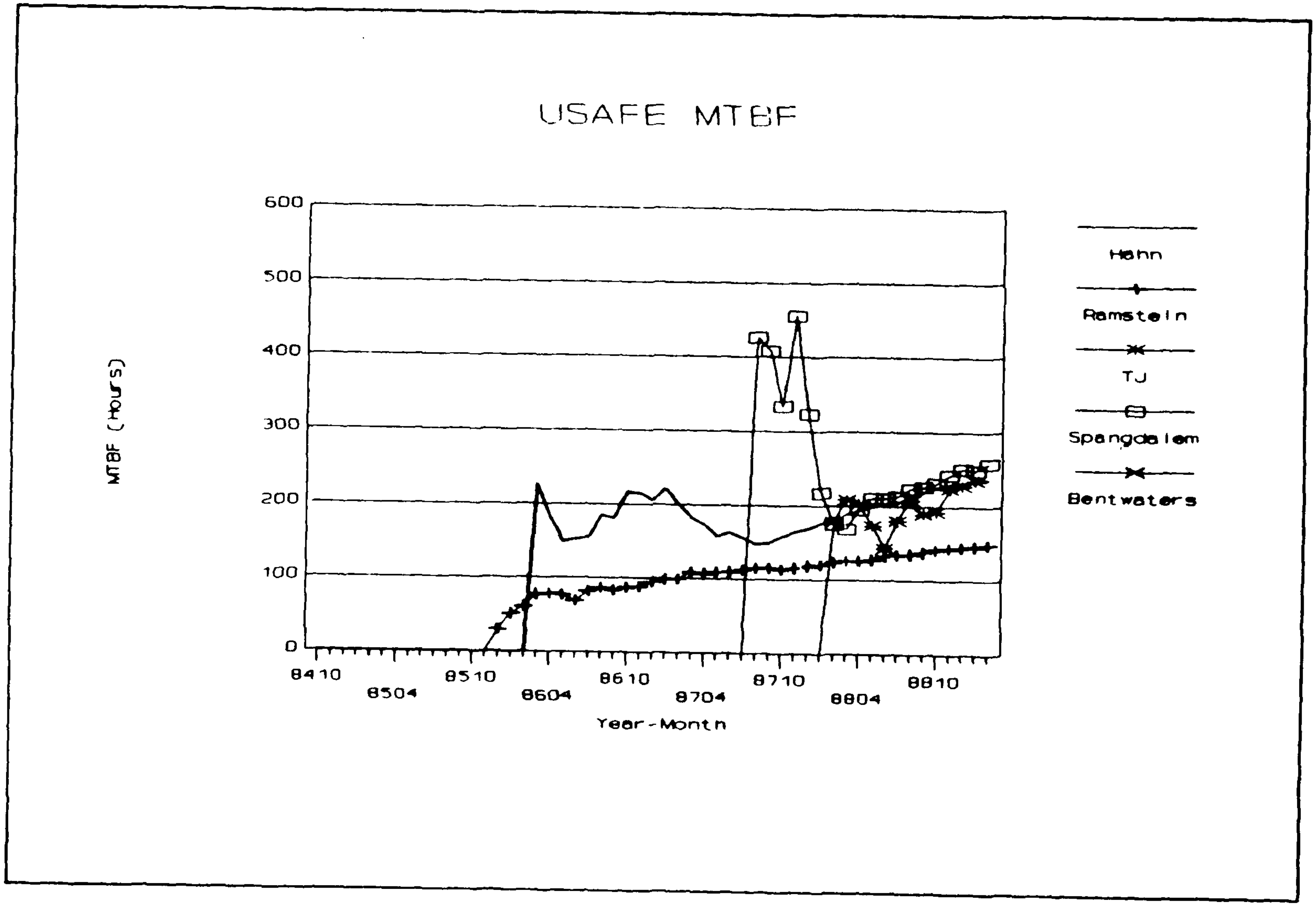

Figure 4. USAFE Failure Trend

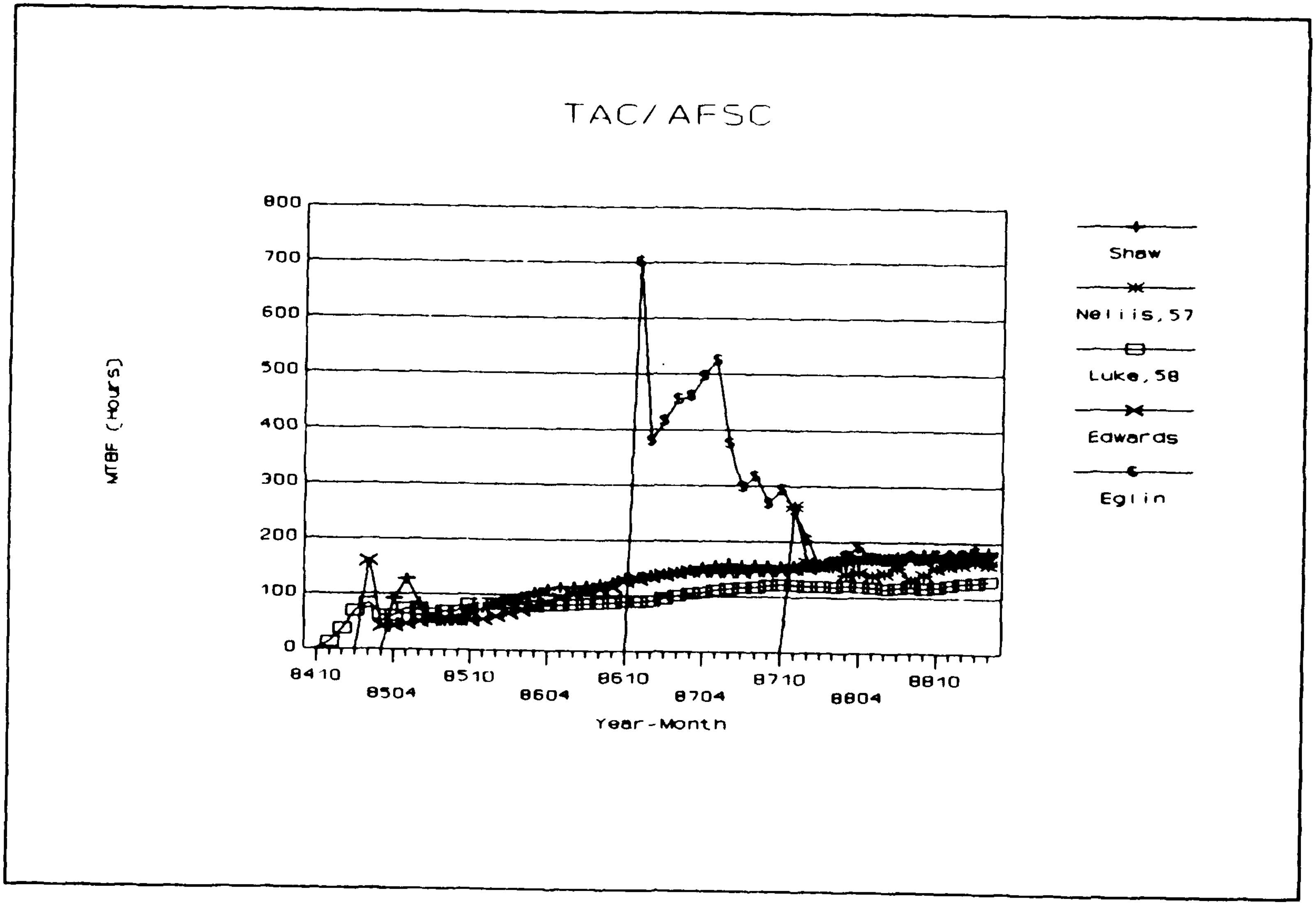

Figure 5. TAC/AFSC Failure Trend

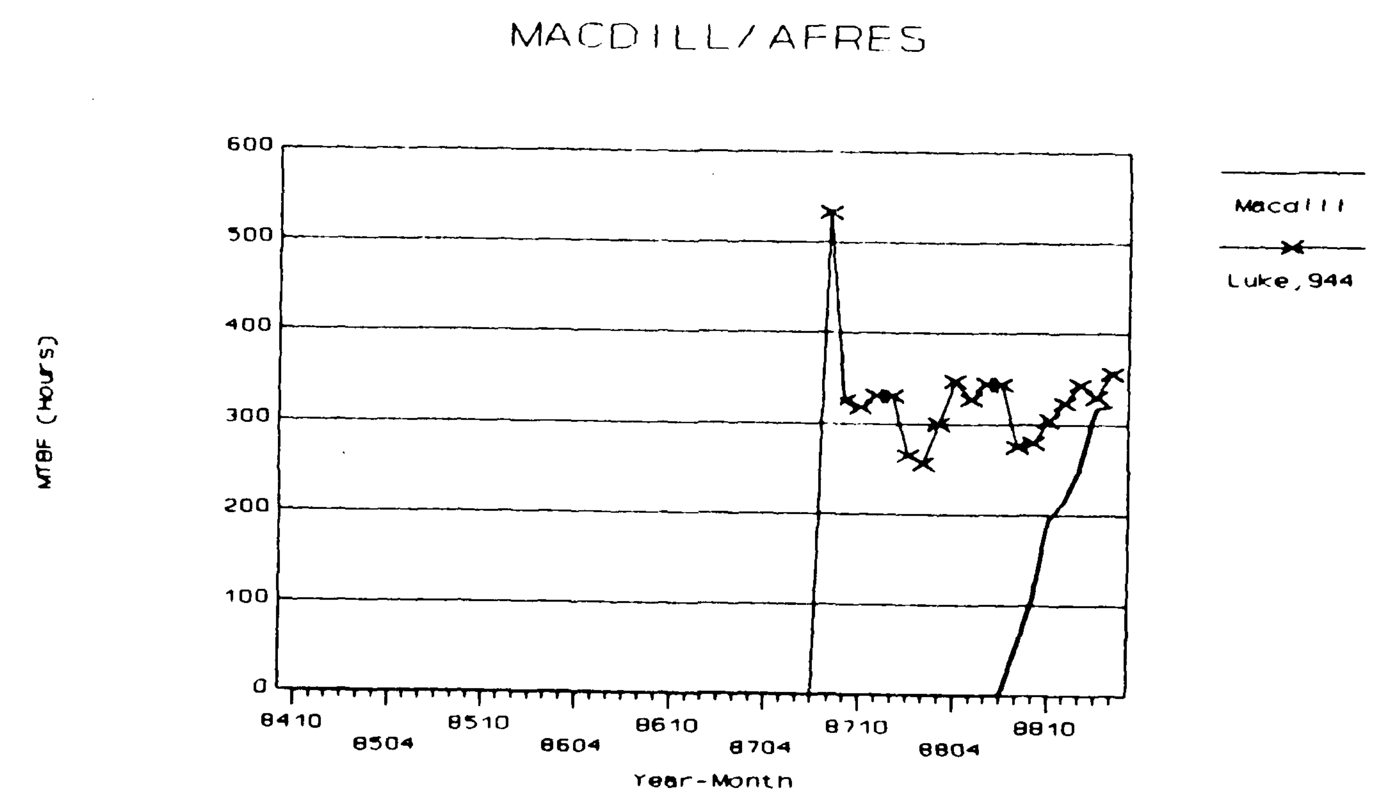

Figure 6. MACDILL/AFRES Failure Trend

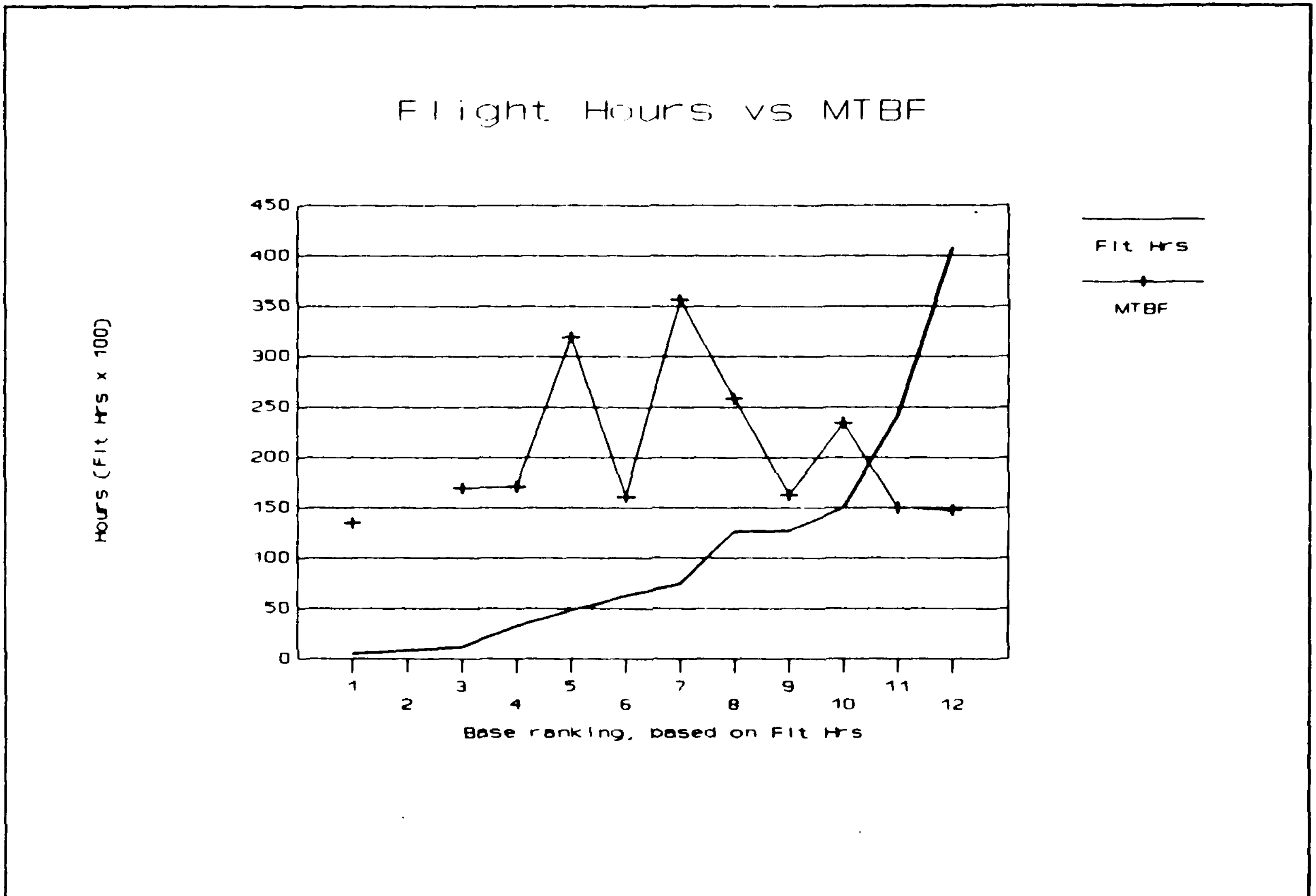

Figure 7. Cumulative Flight Hours versus MTBF

Considering Figures 3 through 6 the system can be simplified to four locations based on the common failure characteristics. These four locations, as the graphs show, are PACAF, USAFE, TAC/AFSC (combined), and Macdill/AFRES combined). Several observations can be made concerning these graphs. Three of the locations (PACAF, TAC/AFSC, and Macdill/AFRES) appear to have reached points of equilibrium for Mean Time Between Failure (MTBF). These points of equilibrium show the respective bases exhibiting constant failure rates. A constant failure rate corresponds to the flat portion of the reliability bathtub curve and is statistically represented by an exponential failure rate. As explained in Chapter III, the distribution of failures for the DMT was expected to be distributed exponentially. Note that the Kolmogorov-Smirnov test and the Chi-Square Goodness-of-Fit test are not considered necessary in this determination.

A combination of Macdill with the Air Force Reserve unit at Luke may seem strange since Macdill is a TAC base, but Macdill is also a training base for the F-16s. This distinguishment, as well as the difference in MTBF, seemed adequate to separate Macdill from the other TAC bases.

The failure trends for the USAFE bases, as given in Figure 4, raise a few more questions. First, the Ramstein failure trend appears to be lower than the other three bases

plotted. No good explanation is known for this discrepancy. Differences in maintenance practices and in reporting could have caused such differences, but no specifics are known. The argument could be made to place Ramstein with the TAC/AFSC bases since the distributions appear to be more similar. This categorization, however, would be inconsistent with the apparent natural groupings of all bases by geographical location/ command. The decision was made to maintain Ramstein with the other USAFE bases.

Bentwaters is listed on the legend as one of the USAFE bases but is not plotted on the graph. At the time of this study, Bentwaters had very few flying hours and no DMT failures. An MTBF of infinity is difficult to graph. Bentwaters was assumed to have the same failure characteristics as the other USAFE bases.

The apparent failure trend for USAFE is defined by the Hahn, Torrejon (TJ), and Spangdalem curves of Figure 4. This trend line is taken to represent all five bases in this analysis. To complicate matters, the USAFE MTBF trend line is climbing while the trends for the other three graphs are fairly level. This trend implies reliability growth for the DMT at USAFE. The problem with reliability growth is that future growth cannot be guaranteed; the growth period may have reached its limit such that the trend will level-off. This occurrence is quite possible and will be assumed for

the following two reasons. First, the USAFE cumulative MTBF is well above the fleet average; significant additional improvement for USAFE is unlikely, considering that the rest of the fleet is stable. Secondly, since the MTBF has a direct impact on the number of available spares, it would seem appropriate to adopt a conservative view that the reliability growth will now stop. The exponential distribution was again adopted as representative of system operation. Other distributions are later considered in testing the sensitivity of the model.

The categorization of bases assumed that all other system parameters are equal or can be easily combined. This assumption is generally true. The required time to diagnose/repair the DMT at each base is approximately equal. The flying hours, number of assigned aircraft, and number of available spares differs between the various bases, but these parameters are simply added together to define the new "base."

The actual time in pipeline for each of the bases was expected to be somewhat different. The geographic location determines the transportation time from that base to the common depot with overseas bases assumed to require longer times than those in the CONUS. The complication of different pipeline times was minimized for two reasons. First, the grouping of bases by major command was largely a

geographical categorization with each base having similar pipeline times. As such, there was consistency within each group. More importantly, the pipeline time obtained from the DMT Item Manager Specialist was an average time for all F-16C/D bases, not distinguishing between CONUS and overseas. An appropriate modification for future consideration would be to insert average pipeline times for each geographical area/major command. This modification, however, should have little effect on the system operation.

With the selection of the four groups, the corresponding system parameters were determined. To obtain the Mean Times Between Failure the total flying hours for all bases in a location was divided by the total number of failures. The number of assigned aircraft and average number of flying hours per year were simply added from each base in the grouping. The initial number of spares assigned to each base was the same as the number of aircraft assigned. The 50 additional spares were assumed to be surplus for the system as a whole. The resulting system parameters for the four locations are given in Table 3.

The model was then constructed with these parameters in mind. The basic model is included in Appendix A. The ultimate output value desired from the model was the number of available spares at each location (considering a portion of the total number of spares are in maintenance). To

Table 3.
F-16C/D Demographics
by Command/Location

Command/Base	# A/C	Cum Flt Hours	Avg Flt Hours/Yr	Cum MTBF
PACAF				
Osan	22	541	4,643*	135
Kunsan	51	12,731	11,608	78
Misawa	52	24,151	10,499	160
	125	37,423	26,750	154.64
USAFE				
Bent	12	837	3,306*	
Spang	36	12,642	9,144	258
TJ	70	15,015	21,000	234
Ramstein	51	40,753	14,178	148
Hahn	77	55,847	21,252	236
	246	125,094	68,880	200.47
TAC/AFSC				
Edwards	11	1,190	73	170
Eglin	7	3,262	146	171
Nellis	36	6,242	6,179*	161
Luke AFB	59	42,308	13,511	131
Shaw	77	100,602	28,351	183
	190	153,604	48,260	164.28
Macdill/AFRES				
Macdill	56	4,795	11,452	319
Luke AFR	26	7,477	4,948	356
	82	12,272	16,400	340.88

The asterisk denotes an estimated value.

obtain this number (and to have any confidence in it) values representing other areas of the system were also requested to be output such that model performance could be compared to actual system performance. Those parameters requested were the number of aircraft at each base, the number of sorties flown, the number of DMT failures, the number

repaired and the number shipped to the depot for repair. A sample output is included in Appendix B. Also obtainable in the output report is the status of each of the queues in the model. The depot queue status is of particular interest and is included.

Validation.

Comparison to Other Models. The use of other models for the development of this particular application was not as useful as was hoped. The other models provided information on format, some desireable output measures, and the use of specific commands, but provided little guidance on the development of the particular model in mind. The model was all original work, excluding the FORTRAN subroutine to redimension the limits of the model.

Face Validity. The system being modeled is fairly straight forward and easily understood. As such there was little to question concerning the development of the model. Even so, there were occasional questions as to what level of complexity was required or would be acceptable to adequately represent the system. Typical of the questions were the level of detail required in scheduling aircraft for sorties. All that was necessary for this study was the generation of the appropriate number of flight hours so that the correct number of failures would be seen. For modeling purposes, these flight hours could have been generated by one aircraft

at each base, but for the sake of the future flexibility of the model all aircraft were included. Individual sorties were normally distributed at 1.7 hours with a standard deviation of 0.2 and occurred in proportional intervals throughout the years; no attention was given to the type of mission, the time of day, or the season.

Internal Validity. It was highly desireable to get the same results from each run of the model, but this was dependent on the modeling techniques and the system being modeled. The system model, provided in Appendix A, produced very precise results for each run but provided somewhat different results between runs. The implications will be more fully addressed under the discussions of run length and the number of runs required.

Reproduction of Past Data. Throughout the model's development it was necessary to compare the results from the running of the model to actual system operation to insure that the modeling was being properly developed. The process was sometimes confusing; the difference between an output value and the expected value for system operation could be attributed to model discrepancy or to the natural variation in system output. Sometimes multiple runs were necessary to insure that the model was valid.

Model Parameter Initialization

Once a valid model was obtained, the determination of starting conditions, run length and number of runs was next required.

Starting Conditions. As explained in Chapter III, data generated from the model during a warm-up period distorts the statistics generated by the model. A determination was needed to as to when this warm-up period is completed. In this situation, a picture is truly worth a thousand words. (Note Figure 8.)

As can be seen from Figure 8, the warm-up period for the system seems to be somewhere just below 20,000 hours. The 20,000 hour mark was the point selected for the completion of the warm-up period; for the calculation of statistics, only data after 20,000 hours was be used.

Run Length. The batch means method was employed to determine the shortest acceptable length for a simulation run. A one year interval size and 16 years runs length was selected to generated 16 intervals. An Analysis of Variance (ANOVA) was performed to compare the means with the established ninety percent confidence level.

The first test resulted in an inability to reject the original hypothesis (the null hypothesis) that the means were equal. The means were assumed to be equal for the two halves. As such, a time frame smaller than eight years was

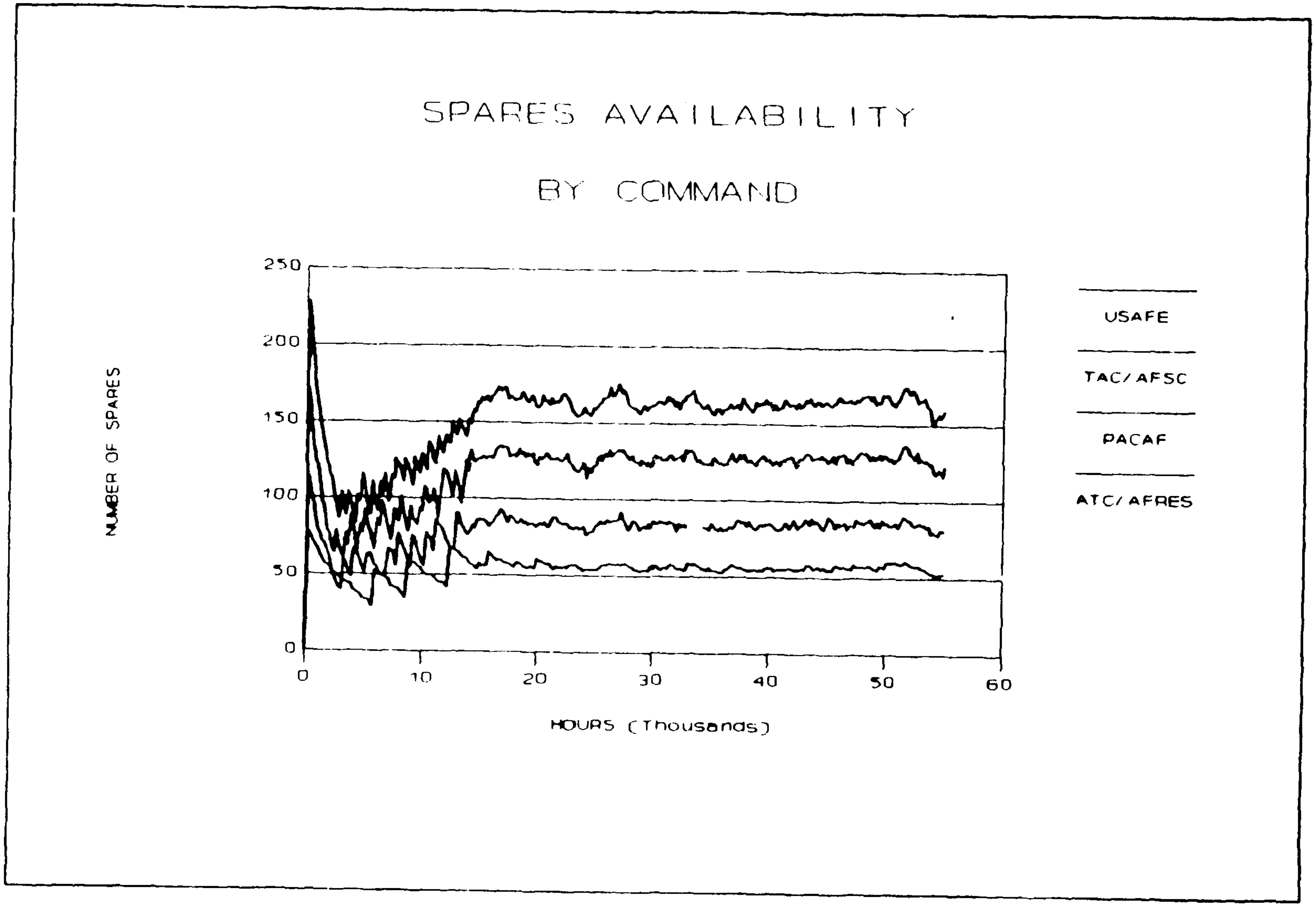

Figure 8. Spares Availability: Model Stabilization

considered. Each of the two eight-year intervals were divided in half, and the means of all four four-year intervals were compared in similar fashion. This, too, resulted in an inability to reject the null hypothesis. A final analysis was done for eight groups of two years each. This was the smallest grouping allowed, considering the one-year interval initially established. The result, again, was the inability to reject the null. It was then assumed that the mean value of the number of available spares at each of the four locations was no more precise at 16 years than at two; a two-year run length would suffice. This calculation was not overly surprising, considering the curves displayed in Figure 8. The number of spares seems to have leveled off very nicely with little variation other than a random fluctuation.

A two-year run length did not seem overly excessive until the number of necessary runs was considered. (The number of necessary runs will be discussed in the following section.) Realizing the potential enormous amount of computer time required and the shortage of time available, the previous calculations were repeated for a basic interval of three months and an eight year span (32 intervals). The three month interval was chosen because six months was the smallest timeframe thought acceptable for the study. The ANOVA again showed that the smallest interval was equally

acceptable. A six month (4380 hours) run length and a 20,000 warm-up period was established for all future runs of the model. Appendix C gives the results of the Analysis of Variance.

Number of Runs. The equation for the required number of runs, as given in Chapter III, is as follows:

$$n = \frac{(Z_{\alpha/2})^2 * \sigma^2}{E^2} \qquad (14:131)$$

where
α = the confidence coefficient,
Z = standard normal Z-score
σ = standard deviation of the population,
E = one-half the confidence interval, and
n = the number of runs required.

For this equation, $\alpha = 0.10$ and $Z_{\alpha/2} = 1.65$. The measured sample standard deviation had more variance between samples than expected. A determination was made to take an average of the standard deviations for each of 30 runs to determine an appropriate value for the population standard deviation. The average of the 30 means and the 30 standard deviations are given in Table 4.

By reviewing the equation for the calculation of the number of runs, it can be shown that the only variable in the equation is the standard deviation. This being the case, the highest value of standard deviation of the four groups above was selected as being the limiting factor on the number of runs necessary.

Table 4.
Spares Availability:
Average Values for 30 Runs

	Means	Std Dev
PACAF	84.0	2.51
USAFE	163.6	4.23
TAC/AFSC	127.0	3.43
MACDILL/AFRES	56.4	1.71
SURPLUS	50.0	
TOTAL	481.0	

The number of runs were calculated as follows.

$$n = \frac{(Z_{\alpha/2})^2 * \sigma^2}{E^2} \qquad (14:131)$$

$$n = \frac{1.65^2 * 4.23^2}{3^2} = 5.41 = 6 \text{ runs}$$

As previously stated, much of the preliminary work had been done using 30 replications instead of the six calculated here. Many runs of the model had also been accomplished using eight replications. All runs of the model having one-half year operating time, 20,000 hour warm-up, and six or more replications are assumed to provide accurate and precise information on the availability of spares at the four locaticns given.

Analysis of Simulation Data

Analysis of Basic Model. Since 30 replications provides acceptable output values for the number of available spares, then the values given in Table 4 provide the current expected values for system operation. It is important to note that the model assumes that all DMTs are distributed to the base sites when repaired as opposed to being stored in a depot warehouse until requested. As such, the available spares shown at the four locations and the 50 held in reserve represent the total number of spares available for use. The model was designed such that a proportional number of spares were assigned to each location in respect to the number of aircraft assigned. As such, the number of available spares at each location are more simply represented by the number of available spares for the system as a whole. At the system level 481 spares are expected to be available for immediate use. (Note Table 5.)

Sensitivity Analysis. All work up to this point was done to develop a model that adequately represented the current maintenance and supply system for the F-16C/D Dual Mode Transmitter. With the baseline established, modifications were made to the system with the differences noted.

Table 5.
Distribution of Spares:
Average Values for 30 Runs

	Total Number	Number Available	In Pipeline
PACAF	125	84.0	41.0
USAFE	246	163.6	82.4
TAC/AFSC	190	127.0	63.0
MACDILL/AFRES	82	56.4	25.6
SURPLUS	50	50.0	0.0
TOTAL	693	481.0	212.0

The approach addressed in Chapter III for comparing the different sensitivity analyses was used. Variations of plus or minus five percent from the baseline values were the levels of interest and are given in Table 6.

Table 6.
Spares Availability:
Variations About Baseline

	- 5%	Baseline	+ 5%
PACAF	79.8	84.0	88.2
USAFE	155.4	163.6	171.8
TAC/AFSC	120.7	127.0	133.4
MCD/AFRES	53.6	56.4	59.2
SURPLUS	(50.0)	(50.0)	(50.0)
TOTAL	459.5	481.0	502.6

In the circumstances where the variation of model parameters in both directions did not make sense, the sensitivity was examined for changes in only the one

direction. The points of reference for all analyses were the average levels of available spares obtained from the run of the basic model for six months plus a 20,000 hour warm-up period and for six or more replications.

The Mean Time Between Demand (MTBD), Not Repairable This Station (NRTS) rate, the number of flying hours, the number of depot servers, and the depot repair transit times were determined to be good candidates for sensitivity analyses. Note that MTBF and MTBD are directly related by a simple ratio, thus eliminating the necessity for a sensitivity analysis for both. Analysis on the MTBF was omitted. For the purposes of this model the NRTS rate was determined to relate directly to the repair rate and the BCS rate; the repair rate and the BCS rate were set equal and collectively consumed all maintenance actions not otherwise ending in a NRTS. As such, only the NRTS rate was evaluated.

MTBD. A sensitivity analysis on the Mean Time Between Demand (MTBD) was performed. The estimated MTBD was derived from the Mean Time Between Failure, MTBF, which was extracted from CDS data. CDS provided the most conservative estimate of all referenced sources for the MTBF, suggesting that a higher value for the MTBF might be considered. It was also determined unlikely that the MTBF (or MTBD) would fall any time in the future. Therefore, the model was

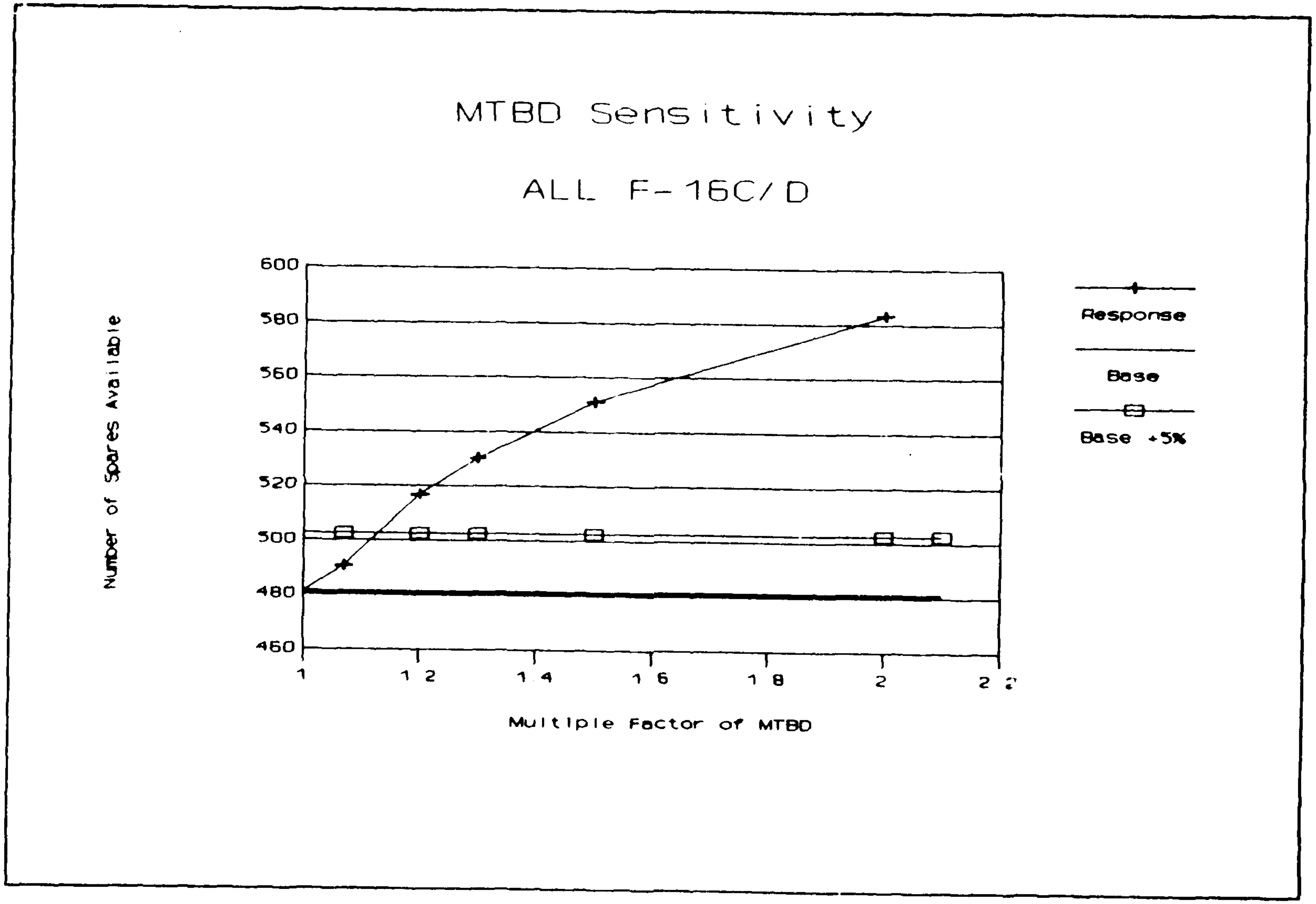

Figure 9. MTBD Sensitivity

subjected to variations in the MTBD, but only in the positive direction. A five percent change in the number of available spares was determined as a useful point of reference for each of the sensitivity analyses. A graph depicting multiples of the original MTBD versus available spares is provided in Figure 9 with the five percent change plotted as a reference. The figure shows that by adjusting the MTBD upward by a factor of approximately 1.15 that a 5% increase in the number of available spares will be seen.

Flying Hour. A sensitivity analysis was also performed on the flying hours as is shown in Figure 10. As with the MTBD, the number of flying hours for the F-16C/D were assumed to be stable or increasing. Figure 10 shows that an increase in the total flying hours by a factor of approximately 1.11 will result in a reduction in the number of available spares by five percent.

Number of Depot Servers. An analysis for the number of depot servers was actually done during the development of the model. The number of depot test stations was known, but the utilization of these stations was not known. A ten day average depot repair cycle and the ability to repair 45 DMTs per month were the limiting constraints for the development of the model. The model was extremely sensitive to the number of theoretical servers at the depot; having one too few resulted in a backlog of spares at the

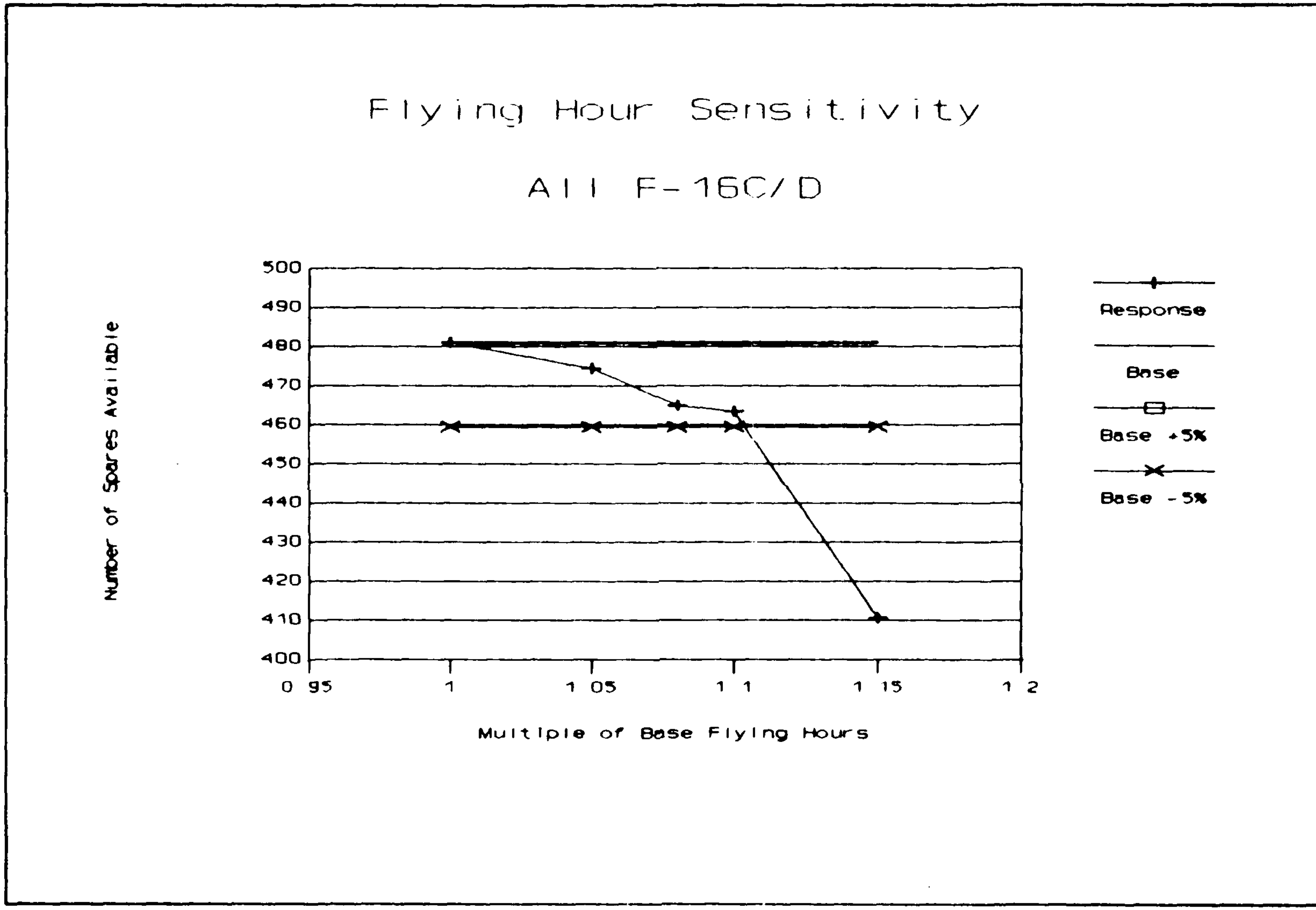

Figure 10. Flight Hour Sensitivity

depot and a reduction of the number available at the bases. Having more than the minimum required number of servers had no effect on the number of spares available, as expected. Figure 11 shows that the minimum required number of servers for the depot at approximately 23 servers. To refrain from planning on 100 percent utilization of the depot, the number of servers in the base model was set at 25.

<u>Transit Time</u>. The transit time shown in Figure 12 is the total of the times to and from the depot. Lengthening the transit times places more assets in transit and reduces spares availability. A comparison of transit times and available spares is provided. The depot service time is not considered in this analysis and is not modified. From Figure 12 it can be seen that a reduction of roughly 10 days off the transit time will result in a five percent increase in the number of spares while an increase of 10 days transit time results in a decrease of five percent.

<u>NRTS</u>. The NRTS rate was varied from 60 to 100 percent, covering the entire expected range. The base NRTS rate was established at 72.5 percent, in slight contrast with some other sources of data. Figure 13 shows that a reduction of the NRTS rate by 10 percent would result in an increase in the number of available spares by five percent. Similarly, an increase in the NRTS rate by 10 percent would show a decrease in the number of spares by five percent.

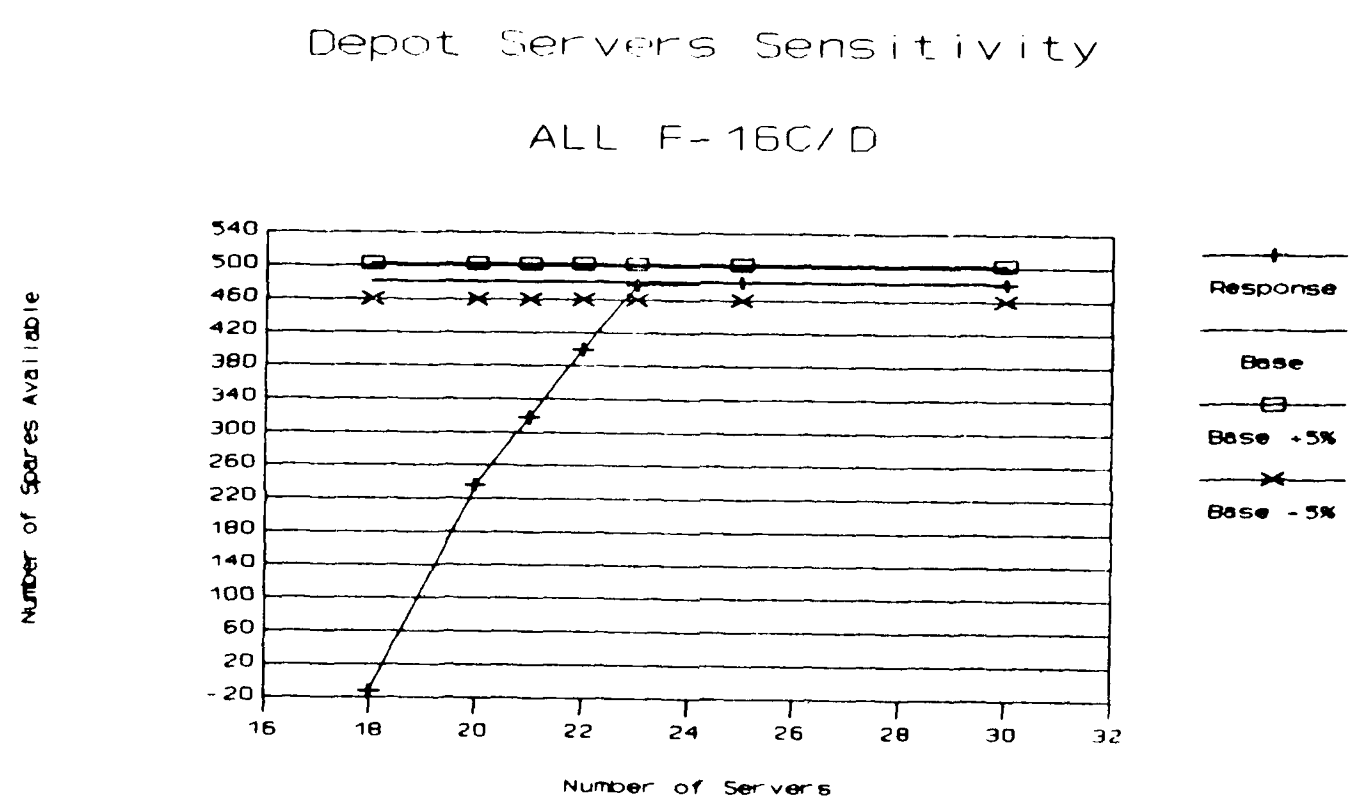

Figure 11. Depot Server Sensitivity

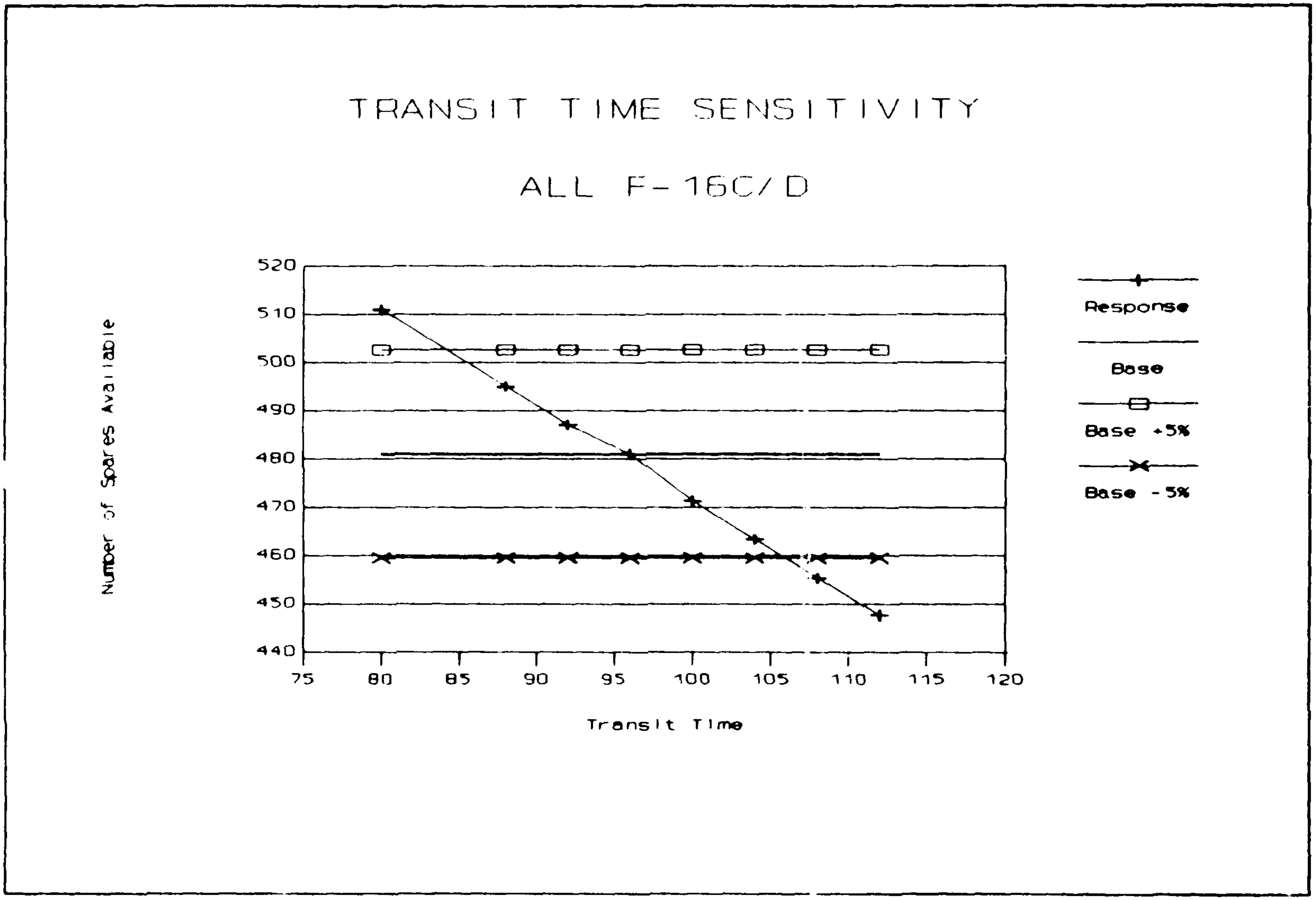

Figure 12. Transit Time (Depot) Sensitivity

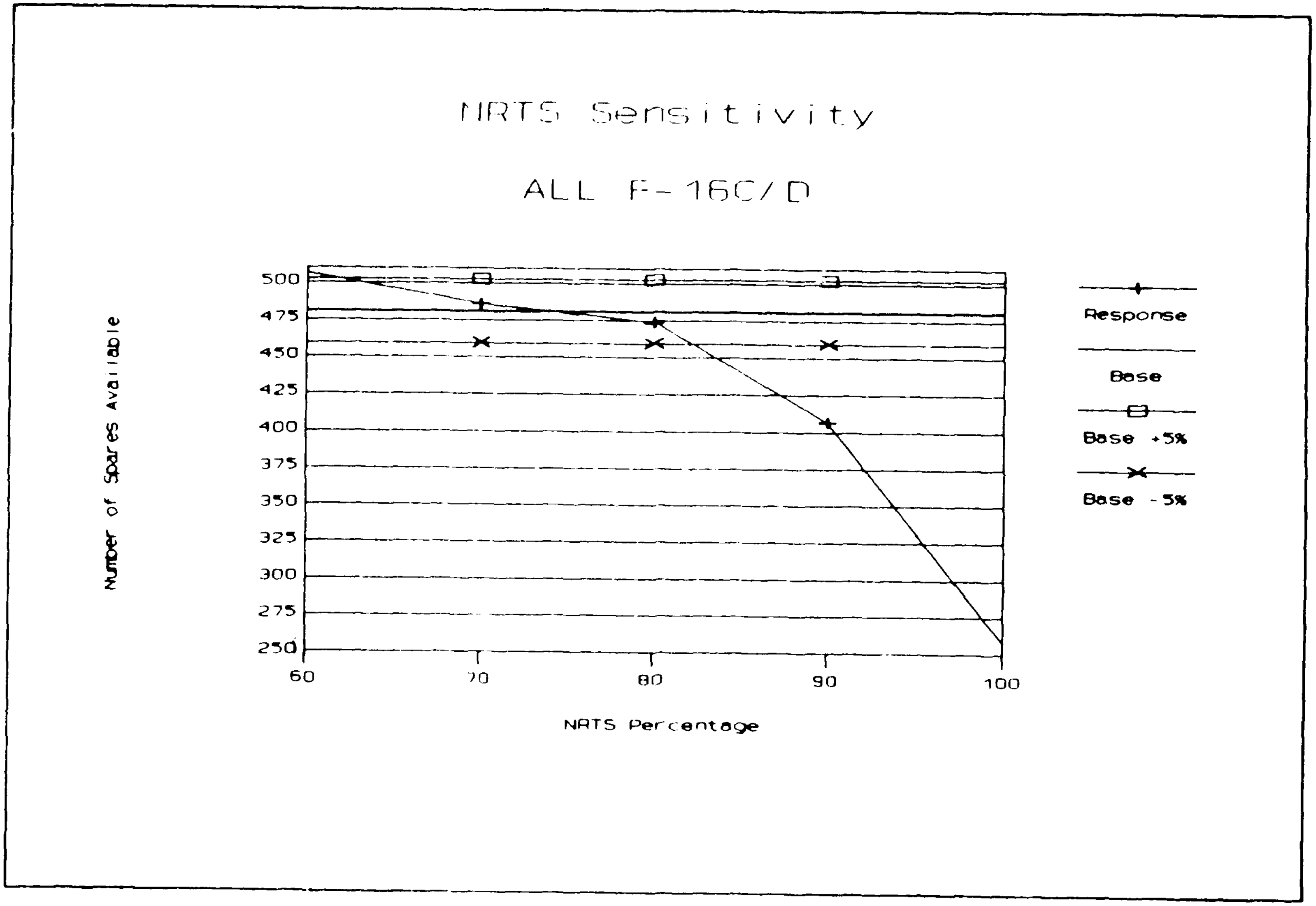

Figure 13. NRTS Sensitivity

The establishment of a NRTS rate of 100 percent is equivalent to a decrease to two levels of maintenance, (as long as there is no time spent diagnosing the problem, which is the case with this model). Examining the 100 percent NRTS rate on Figure 13 shows that the number of available spares drops down to 258 spares, a drop of 223 spares from the base level of 481. The possibility of two-level maintenance will be discussed more fully in the following section.

Two-Level Maintenance.

Peacetime. As explained previously, adjusting the model to 100 percent NRTS is equivalent to changing to a two-level maintenance structure in that it eliminates the intermediate level of maintenance. The sensitivity analysis on the NRTS rate showed that 100 percent NRTS results in the availability of 258 spares which is 223 spares lower than the original level of 481.

The War Readiness Spares Kit (WRSK) requirement, as stated in Chapter III, is 351 spares. The number of replacement spares required in base supply is 120. Collectively, 471 available spares are needed to support the peacetime mission. The 100 percent NRTS level of 258 spares does not meet this requirement unless future buys of the DMT are also considered. Currently, 290 additional spares are on contract for acquisition. This 290 plus the 258 spares

available (assuming 100 percent NRTS) makes 548 available spares. This quantity is adequate to meet the peacetime flying mission.

Wartime: 30 Day Surge. The basic model was modified to represent possible wartime flying requirements. A 30 day wartime surge was imposed on the peacetime flying model (at equilibrium) for an NRTS rate of 72.5 percent. The 30 day surge was represented by flying each aircraft two sorties per day. The increased number of flying hours were imposed following a one-half year peacetime flying scenario (after reaching equilibrium in the model). All 643 aircraft were flown for the 30 day war, and the current level of 1.7 flying hours per sortie was maintained. The model was run for 6 replications with the initial number of spares being 983 (the original 693 plus an acquisition of 290 additional spares). The number of available spares dropped steadily with each passing day such that an average quantity is not appropriate; however, the spares quantities at the end of the 30 day period is essential for examining the operation of the system. The model shows that 541 spares are expected to be on-hand at the end of the 30 day period, assuming the current 72.5 percent NRTS rate.

This same model was again run assuming 100 percent NRTS (two-level maintenance). The results were not that much different from two-level maintenance in that 325 spares are

now expected. This spares level is more than adequate to meet the requirements.

A wartime situation will encourage different operating conditions in many areas. While most of these differences cannot be accounted for, some may be rationally expected and may be included in the model. A surge of depot maintenance capability is highly likely. Assuming only current capabilities and an expansion from two to three maintenance shifts at the depot will result in 37 equivalent servers for depot maintenance. Rerunning the model with 37 depot servers again showed an expected availability of 541 spares at the 72.5 percent NRTS level and 325 spares at 100 percent NRTS. The change in depot capacity did not affect the level of spares based on a 30 day wartime surge. (See Table 7.)

Table 7.
Spares Availability:
30 Day Wartime Surge

	Number of Servers	
	25	37
72.5% NRTS	541	541
100% NRTS	325	325

Comparing this information against the model for validity showed that the transit time to and from the depot was 44 days or more. The first failure of a DMT would not

reach the depot (as modeled) prior to the end of a 30 day conflict, nor would a depot repaired DMT reach the field in this same timeframe. It would therefore seem obvious that the depot capability was not a factor in such a scenario.

The model, however, could be modified to examine the system response to a sustained wartime conflict, which definitely would consider depot capacity. This adjustment to the model was accomplished, as follows.

Wartime: Sustained Conflict. For a sustained war, the sortie rate has an expected value of 1.5 sorties per day (1). Again, the length of the sortie was not known but was assumed to equal the current operating sortie length of 1.7 hours. As such, the number of flight hours per aircraft were estimated for a year as an input to the model. The model was run for a warm-up period of 20,000 hours. It was operated for one-half year under peacetime conditions and then was subjected to the flying hours corresponding to 1.5 sorties per day. The model was run using both 25 and 37 depot servers and was run for 6 replications each time. The initial number of spares in the system was again assumed to be 983.

The model was first run using the assumption of 25 servers. The model was allowed to stabilize in order to evaluate the sustained war conditions. The level of spares was totally unacceptable showing that the system would have

a shortage of 430 spares; only 213 of the 643 aircraft would have working DMTs at any given time.

An expansion of depot repair capability by 50 percent was then simulated by adjusting the number of servers to 37. The model corresponding to 72.5 percent NRTS and 37 servers showed a shortage of 330 spares. The transit time was then modified to three-quarters and half the normal time with the system gaining about 10 spares under each scenario. Even though a spares level of -330 spares is quite unacceptable, it can be seen that the backlog in the system is at the depot and not the time in transit for the spares. Further modifications to the system for wartime operation should emphasize additional depot capabilities.

System operation in wartime conditions and two-level maintenance would show even worse spares levels than was shown with three level maintenance; however, an ennancement of depot capabilities could possibly make two-level maintenance viable for a sustained war. Adjusting only the number of depot servers in a sustained war gives the results shown in Table 8.

Summary

The number of available F-16C/D DMT spares was projected for both peacetime and wartime flying requirements. The number of spares were calculated for both

Table 8.
Spares Availability Versus
Number of Depot Servers:
Sustained War

Servers	Levels of Maintenance 2	3
50	-279	-217
75	-83	160
100	49	181

the current three-level maintenance structure with 72.5 percent Not Repairable This Station (NRTS) and for a two-level maintenance structure (100 percent NRTS). Projected levels of spares were based on the current number of spares in the inventory plus pending acquisitions for a total of 983 spares.

The peacetime model for current maintenance practices showed an availability of 481 spare DMTs. (Note Table 9). This number compares favorably with actual estimated quantities for August 1989 (10). This quantity is sufficient to meet the peacetime requirement of having 471 available spares to support WRSK and replacement spares. The two-level maintenance option, on the other hand, is unsatisfactory if only current quantities of spares are considered. All options are acceptable for peacetime operation considering the purchase of an additional 290 spare DMTs, which is pending.

Table 9.
Spares Availability:
Peacetime Summary

	(693 Spares) Number of Servers		(983 Spares) Number of Servers	
	25	37	25	37
72.5% NRTS	481	N/A	771	N/A
100% NRTS	258	N/A	548	N/A

Peacetime Requirements	
WRSK	351
On-Hand	120
Total	471

The 30 day wartime surge projection is similar to the peacetime model in that both the two-level and three-level maintenance structures are viable with the purchase of the additional spares. Only the two-level maintenance option was unacceptable without these spares. The number of depot servers did not contribute to this analysis because of the length of the transit time to and from the depot. The requirement to maintain a balance to support WRSK was dropped for all wartime situations. (Note Table 10).

Sustained wartime operations were also analyzed. Neither the current three-level maintenance structure nor the proposed two-level structure can support a sustained conflict with the current quantity of spares. The addition of the 290 spares currently on contract do not bring the spares up to an acceptable level. The shortage of spares occurs because of a backlog at the depot. Shortening the

Table 10.
Spares Availability:
Wartime Summary

Wartime: 30 Day Surge

	(693 Spares) Number of Servers		(983 Spares) Number of Servers	
	25	37	25	37
72.5% NRTS	199	199	489	489
100% NRTS	-45	-46	244	244

Wartime: Sustained War

	(693 Spares) Number of Servers		(983 Spares) Number of Servers	
	25	37	25	37
72.5% NRTS	N/A	N/A	-430	-330
100% NRTS	N/A	N/A	-473	-367

transit time or adding additional spares did little to alleviate the problem, but the addition of depot servers addressed the problem directly; either maintenance option could be made viable if enough depot maintenance support was made available. It was found that 75 to 100 servers would be required to support two-level maintenance and 50 to 75 servers would be required for three-level. (See Table 8.) Since current depot capability is represented by 25 servers, then the number of servers required actually corresponds to three to four times the current depot capacity for two-level maintenance and two to three times the capacity for three-level maintenance.

In conclusion, two-level maintenance will support both the peacetime conditions and a 30 day wartime surge.

Neither the two-level maintenance structure nor the three-level maintenance structure will support a sustained war without additional depot support. Between 2 and 3 times the current depot capability is required for three-level maintenance to support a sustained war while 3 to 4 times the current capability is required for three-level maintenance. With the realization that additional depot support would be required to support a sustained war with any maintenance option, it may be stated that two-level maintenance is a viable option.

Chapter V. Conclusions

Overview

The primary objective of this study was to provide a valid model of the maintenance and supply system of the F-16C/D Dual Mode Transmitter for the examination of spares availability. The chief purpose of this model was to determine whether a reduction to two levels of maintenance for the DMT is viable. The research questions of Chapter I provided the focus for the development of the model and the determination of the level of maintenance. This chapter provides a review of the research questions and some recommendations for future study.

Research Questions

1. What is the best method/model to evaluate the Dual Mode Transmitter maintenance and supply system for the determination of spares availability?

The stochastic nature of the system suggests that a deterministic analysis may be less than optimal. The backlog of depot maintenance, for example, is very difficult to work with analytically but can be easily modeled using simulation. SLAM II was chosen as the simulation language.

2. Does this method/model measure what it claims to measure?

Each portion of the model was developed and compared to known operating conditions. This was necessary to insure the integrity of the model. Appropriate groupings of bases were carefully considered for modeling purposes. These groupings provided good insight to the actual system operation. Various methods of validation and verification were employed to insure that both the model and output are accurate.

3. Can this method/model be generalized to other components within the F-16C/D?

It was important that critical system parameters be easy to change. Therefore, these parameters were placed in the beginning of the model for easy access and modification. The ease of access benefits both the sensitivity analyses and the generalization to other components. This design enabled easy modification to represent the wartime scenario. The selected classification of bases can hinder the use of this model for other F-16C/D components; another component may or may not fit this classification well. To avoid this problem the model could be expanded to represent the total number of bases individually instead of having four general categories.

4. What modifications to the three-level maintenance structure are currently proposed to improve the availability of spares for the DMT?

No reliability improvements are currently scheduled for the DMT. An elimination of the phased noise test at the intermediate level is planned, but this will have no effect on the availability of spares.

5. What other aspects of three-level maintenance on the DMT most greatly affect spares availability of the DMT and can they be controlled/modified?

Sensitivity analyses were performed on five major system parameters. Table 11 shows the required change in the parameters for a five percent change in the number of spares.

Table 11.
Parameter Sensitivity for
Five Percent Change in Spares

Spares - 5%	System Parameter	Spares + 5%
N/A	MTBD/MTBF	+ 7%
+ 10%	Flying Hours	N/A
23	Depot Servers (25)	*
+ 10 days	Transit Time	- 10 days
+ 10%	NRTS	- 10%

* No change occurred when servers were increased

As to which parameters can be modified, the MTBD and NRTS rates cannot be adjusted much without a modification to the DMT itself, and none is planned. The number of flying

hours is dependent on the mission and. therefore, cannot be altered. The number of depot servers can be modified if needed. The justification for increasing the number of servers, though, should be that a backlog exists; no benefit is gained from having surplus servers. Finally, the transit time to and from the dapot can be modified. Expediting can be done throughout the maintenance cycle, but other methods are also available for shortening the transit time. For example, the DMT is shipped to Ogden, Utah prior to being shipped to Maryland for repair. The DMT is returned to Ogden for disbursement after repair. This practice requires an average of 8 days each way. This is one possible area for improvement in transit times.

6. Is the reduction to two levels of maintenance for the F-16C/D DMT with current levels of spares and equipment viable?

A two-level maintenance structure can support either peacetime operating conditions or a 30 day wartime surge. Two-level maintenance cannot support a sustained war without additional depot support, but neither can three-level maintenance. Two-level maintenance would require 3 to 4 times the current depot capacity to support such a war while three-level maintenance would require only 2 to 3 times the current amount. Inasmuch as three-level maintenance is a viable option, two-level maintenance is also viable.

Recommendations for Future Research

Throughout this study the depot capacity was simply modeled by a given number of parallel servers. These servers simulated the workload processed through the depot but did not represent current depot level manpower. In trying to examine all aspects of the system for possible improvements a more exact model representation of the depot would be beneficial.

All bases used a common pipeline time in this study, based on the average pipeline time for all F-16C/D bases. Overseas bases have greater transit times for shipment to the depot than do those in CONUS. A modification of transit times would give a better picture of specific levels of spares in the various locations worldwide.

A secondary product of this study was the categorization of bases into common failure distributions. These groupings showed certain major commands having significantly higher mean times between failures than other commands. A study of the differences in maintenance practices between commands may offer a way to improve the MTBF for the lower bases. An improvement of the MTBF will result in a higher availability of spares.

The categories selected for the DMT may not be appropriate for other Line Replaceable Units. Representing each base individually would avoid this problem, assuming an

appropriate failure distribution can be determined for each base. Actually, this model can be used for any component on any aircraft that employs three levels of maintenance, given the adjustment of all system parameters in the model.

Finally, the sensitivity analysis showed the resulting availability of spares from an adjustment of one of many system parameters. The system response to a change in multiple parameters is not known. A logical follow-on to this study is the development of a factorial design which accounts for the combination of these system parameters and provides the most effective combinations.

Summary

The maintenance and supply system for the Dual Mode Transmitter was modeled to evaluate the availability of spares in the system. Both three-level and two-level maintenance concepts were simulated to see if a reduction to two levels of maintenance was viable. The model was subjected to peacetime conditions as well as a 30 day war and a sustained war. It was discovered that ample spares are in the system to support the expected flying requirements for peacetime conditions and for a 30 day war. Additional depot capability is required to support a sustained war with either three-level maintenance or two-level maintenance.

Based on this study, the recommendation is made to eliminate the intermediate level of maintenance for the Dual Mode Transmitter for a reduction from three levels of maintenance to two levels of maintenance.

Appendix A. The Basic Model

```
GEN,ROB SHELL,A1,07/15/1989,30,,,//,72;
LIMITS,14,6,20000;
TIMST,XX(4),# SPARES 01;
TIMST,XX(14),# SPARES 02;
TIMST,XX(24),# SPARES 03;
TIMST,XX(34),# SPARES 04;
NETWORK;
;
;
==========================================================
      RESOURCE/DMT1(1),11;
      RESOURCE/DMT2(1),12;
      RESOURCE/DMT3(1),13;
      RESOURCE/DMT4(1),14;
      CREATE;
      ACT;
;   ========================================================
;   "BASE" DESIGNATORS
;   -01  PACAF
;   -02  USAFE
;   -03  TAC/AFSC
;   -04  ATC/AFRES
;   ========================================================
;   VARIABLES
;   ========================================================
;   SYSTEM PARAMETERS FOR ALL BASES
      ASSIGN,XX(41)=1.7;                  SORTIE LENGTH
      ASSIGN,XX(42)=0.725;                NRTS RATE
      ASSIGN,XX(43)=0.125;                RTS RATE
      ASSIGN,XX(44)=0.15;                 BCS RATE
;   ========================================================
;   ASSIGNED AIRCRAFT AT EACH "BASE"
      ASSIGN,XX(2)=125;      # A/C AT PACAF
      ASSIGN,XX(12)=246;     # A/C AT USAFE
      ASSIGN,XX(22)=190;     # A/C AT TAC/AFSC
      ASSIGN,XX(32)=82;      # A/C AT ATC/AFRES
;
;        NOTE: TO CHANGE THE NUMBER OF AIRCRAFT
;        ASSIGNED AT EACH BASE, YOU MUST ALSO
;        CHANGE EACH CREATE NODE, CO-
;   =======================================================
;   ADDITIONAL NUMBER OF SPARES AT EACH "BASE"
      ASSIGN,XX(4)=125;      # SPARES AT PACAF
      ASSIGN,XX(14)=246;     # SPARES AT USAFE
```

```
    ASSIGN,XX(24)=190;      # SPARES AT TAC/AFSC
    ASSIGN,XX(34)=82;       # SPARES AT ATC/AFRES
; =============================================================
;  TOTAL "BASE" FLIGHT HOURS PER YEAR
    ASSIGN,XX(6)=26750;     FLT HRS/YR  PACAF
    ASSIGN,XX(16)=68880;    FLT HRS/YR  USAFE
    ASSIGN,XX(26)=48260;    FLT HRS/YR  TAC/AFSC
    ASSIGN,XX(36)=16400;    FLT HRS/YR  ATC/AFRES
; =============================================================
;  CURRENT MTBF
    ASSIGN,XX(8)=154.64;    MTBF AT PACAF
    ASSIGN,XX(18)=200.47;   MTBF AT USAFE
    ASSIGN,XX(28)=164.28;   MTBF AT TAC/AFSC
    ASSIGN,XX(38)=340.88;   MTBF AT ATC/AFRES
;  ============================================================
;  DUMMY VARIABLE
    ASSIGN,XX(60)=0;
;  ============================================================
;  CALCULATIONS
;  ============================================================
;  HOURS BETWEEN SORTIES, NOT INCL FLT TIME
    ASSIGN,XX(6)=8760*XX(2)*XX(41)/XX(6)-XX(41);     PACAF
    ASSIGN,XX(16)=8760*XX(12)*XX(41)/XX(16)-XX(41); USAFE
    ASSIGN,XX(26)=8760*XX(22)*XX(41)/XX(26)-XX(41); TAC/
;                                                    AFSC
    ASSIGN,XX(36)=8760*XX(32)*XX(41)/XX(36)-XX(41);  ATC/
;                                                    AFRES
;  ============================================================
;  PERCENT BROKEN, (1 - PERCENT BCS)
    ASSIGN,XX(5)=1-XX(44);
;  ============================================================
;  MEAN TIME BETWEEN DEMAND
    ASSIGN,XX(8)=XX(8)*XX(5);       PACAF
    ASSIGN,XX(18)=XX(18)*XX(5);     USAFE
    ASSIGN,XX(28)=XX(28)*XX(5);     TAC/AFSC
    ASSIGN,XX(38)=XX(38)*XX(5);     ATC/AFRES
;  ============================================================
    TERM;
;
;
; *********************************************** *****
;   PACAF
; *****************************************************
;
;    THIS FIRST SECTION CREATES THE AIRCRAFT WITH VARYING
;    AMOUNTS OF FLIGHT TIME SINCE LAST FAILURE OF A DMT.
;
C01  CREATE,0,,,125;          CREATE AIRCRAFT
     ACT/1;                   # AC 01
;
```

```
      ASSIGN,ATRIB(2)=EXPON(XX(8));        MTBF
      ASSIGN,ATRIB(1)=UNFRM(0,ATRIB(2)); INIT TIME ON A/C
      ASSIGN,XX(1)=ATRIB(1);
;
;    THE A/C ARE NOW CREATED AND READY TO FLY AND TO FAIL.
;    =====================================================
;
F01   GOON;
      ACT,,XX(60).EQ.0.AND.TNOW.GE.20000,CLR;
      ACT,,,CONT;
;
CLR   ASSIGN,XX(60)=1;
      EVENT,1;
;
CONT  GOON;
      ASSIGN,ATRIB(3)=RNORM(XX(41),.2);  SORTIE LENGTH
      ASSIGN,ATRIB(1)=ATRIB(1)+ATRIB(3); FLT HOURS SINCE
;                                        FAILURE
;
G01   GOON;
      ACT/3,ATRIB(3);                   SORTIES 01
      ASSIGN,ATRIB(4)=0.0;
      GOON;
      ACTIVITY/51,XX(6);                WAIT, PACAF
;
      GOON;
      ACT/4,,ATRIB(1).GT.ATRIB(2),H01; DMT FAIL 01
      ACT/5,,ATRIB(1).LE.ATRIB(2),F01; DMT GOOD 01
;
H01   GOON,1;
      ASSIGN,XX(3)=ATRIB(1);             MTBF
      ASSIGN,XX(4)=XX(4)-1;              DEC'MENT SPARES BY 1
      ACT,,XX(4).LT.0,I01;               NOT ENOUGH.  MICAP
      ACT,,XX(4).GE.0,J01;               ENOUGH SPARES?
;
I01   GOON;
      ASSIGN,XX(2)=XX(2)-1;              DECREMENT # OF A/C
      AWAIT(11),DMT1/1,BLOCK,1;
      ACT;
;
J01   GOON,2;
      ACT,,,L01;
      ACT,,,K01;
;
K01   GOON,1;
      ASSIGN,ATRIB(1)=0.0;
      ASSIGN,ATRIB(2)=EXPON(XX(8));
      ACT,,,F01;
;
L01   QUEUE(1);
```

```
        ACTIVITY(1)/9,2;                              2 HR TST 01
        GOON;
        ACTIVITY/6,,ATRIB(4).NE.1.0,M01;              DIAGNOSE 01
        ACTIVITY/7,,ATRIB(4).EQ.1.0,S01;              POST RPR 01
;
M01     GOON;                                         DIAGNOSED
        ACTIVITY,0,XX(42),P01;                        NRTS
        ACTIVITY,0,XX(44),S01;                        BCS
        ACTIVITY,2,XX(43),N01;                        RTS
;
N01     GOON;
        ACTIVITY;
        ASSIGN,ATRIB(4)=1.0;
        ACTIVITY,,,L01;
;
P01     GOON;                           NRTS TO DEPOT
        ACTIVITY/8,1056,,DEPO;          TO DEPOT 01
;                                       44 DAYS
;
;
;   =====================================================
;
S01     GOON;                           BASE 01 (PACAF) SUPPLY
        ASSIGN,XX(4)=XX(4)+1;
;        COLCT,XX(4),# SPARES 01,52/-125/5;
;
        GOON;
        ACT,,XX(4).GT.0,U01;
        ACT,,XX(4).LE.0,T01;
;
T01     GOON;
        ASS,XX(2)=XX(2)+1;
        FREE,DMT1/1;
        ACT;
;
U01     GOON,1;
;        COLCT,XX(2),# AV_AC 01,50/25/2;
        TERM;
;
; ****************************************************
;    USAFE
; ****************************************************
;
;    THIS FIRST SECTION CREATES THE AIRCRAFT WITH VARYING
;    AMOUNTS OF FLIGHT TIME SINCE LAST FAILURE OF A DMT.
;
C02     CREATE,0,,,246;              CREATE AIRCRAFT
        ACT/11;                      # AC 02
;
        ASSIGN,ATRIB(2)=EXPON(XX(18));      USAFE MTBF
        ASSIGN,ATRIB(1)=UNFRM(0,ATRIB(2)); INIT TIME ON A/C
```

```
        ASSIGN,XX(11)=ATRIB(1);
;
;      THE A/C ARE NOW CREATED AND READY TO FLY AND TO FAIL.
;      ======================================================
;
F02     GOON;
        ACTIVITY;
        ASSIGN,ATRIB(3)=RNORM(XX(41),.2);  SORTIE LENGTH
        ASSIGN,ATRIB(1)=ATRIB(1)+ATRIB(3); FLT HRS SINCE
;                                          FAILURE
;
G02     GOON;
        ACT/13,ATRIB(3);                   SORTIES 02
        ASSIGN,ATRIB(4)=0.0;
        GOON;
        ACTIVITY/52,XX(16);                WAIT, USAFE
        GOON;
        ACT/14,,ATRIB(1).GT.ATRIB(2),H02;  DMT FAIL 02
        ACT/15,,ATRIB(1).LE.ATRIB(2),F02;  DMT GOOD 02
;
H02     GOON;
        ASSIGN,XX(13)=ATRIB(1);          MTBF
        ASSIGN,XX(14)=XX(14)-1;          DECREMENT SPARES BY 1
        ACT,,XX(14).LT.0,I02;            NOT ENOUGH SPARES.
;                                        MICAP
        ACT,,XX(14).GE.0,J02;            ENOUGH SPARES?
;
I02     GOON;
        ASSIGN,XX(12)=XX(12)-1;          DECREMENT # OF A/C
        AWAIT(12),DMT2/1,BLOCK,1;
        ACT;
;
J02     GOON,2;
        ACT,,,L02;
        ACT,,,K02;
;
K02     GOON,1;
        ASSIGN,ATRIB(1)=0.0;
        ASSIGN,ATRIB(2)=EXPON(XX(18));
        ACT,,,F02;
;
L02     QUEUE(2);
        ACTIVITY(1)/19,2;                        2 HR TST 02
        GOON;
        ACTIVITY/16,,ATRIB(4).NE.1.0,M02;        DIAGNOSE 02
        ACTIVITY/17,,ATRIB(4).EQ.1.0,S02;        POST RPR 02
;
M02     GOON;                                    DIAGNOSED
        ACTIVITY,0,XX(42),P02;                   NRTS
        ACTIVITY,0,XX(44),S02;                   BCS
```

```
        ACTIVITY,2,XX(43),N02;                          RTS
;
N02     GOON;
        ACTIVITY;
        ASSIGN,ATRIB(4)=1.0;
        ACTIVITY,,,L02;
;
P02     GOON;                               NRTS TO DEPOT
        ACTIVITY/18,1056,,DEPO;             TO DEPOT 02
;                                           44 DAYS
;
;   ======================================================
;
S02     GOON;                               BASE 02 (USAFE) SUPPLY
        ASSIGN,XX(14)=XX(14)+1;
;        COLCT,XX(14),# SPARES 02,50/-246/10;
;
        GOON;
        ACT,,XX(14).GT.0,U02;
        ACT,,XX(14).LE.0,T02;
;
T02     GOON;
        ASS,XX(12)=XX(12)+1;
        FREE,DMT2/1;
        ACT;
;
U02     GOON;
;        COLCT,XX(12),# AV_AC 02,50/146/2;
        TERM;
;
;   ******************************************************
;     TAC/AFSC
;   ******************************************************
;
;     THIS FIRST SECTION CREATES THE AIRCRAFT WITH VARYING
;     AMOUNTS OF FLIGHT TIME SINCE LAST FAILURE OF A DMT.
;
C03     CREATE,0,,,190;             CREATE AIRCRAFT
        ACT/21;                     # AC 03
;
        ASSIGN,ATRIB(2)=EXPON(XX(28));      TAC/AFSC MTBF
        ASSIGN,ATRIB(1)=UNFRM(0,ATRIB(2)); INIT TIME ON A/C
        ASSIGN,XX(21)=ATRIB(1);
;
;    THE A/C ARE NOW CREATED AND READY TO FLY AND TO FAIL.
;    =====================================================
;
F03     GOON;
        ACTIVITY;
        ASSIGN,ATRIB(3)=RNORM(XX(41),.2);  SORTIE LENGTH
```

```
        ASSIGN,ATRIB(1)=ATRIB(1)+ATRIB(3); FLT HRS SINCE
;                                          FAILURE
;
G03     GOON;
        ACT/23,ATRIB(3);                  SORTIES 03
        ASSIGN,ATRIB(4)=0.0;
        GOON;
        ACTIVITY/53,XX(26);               WAIT, TAC/AFSC
        GOON;
        ACT/24,,ATRIB(1).GT.ATRIB(2),H03; DMT FAIL 03
        ACT/25,,ATRIB(1).LE.ATRIB(2),F03; DMT GOOD 03
;
H03     GOON;
        ASSIGN,XX(23)=ATRIB(1);          MTBF
        ASSIGN,XX(24)=XX(24)-1;          DECREMENT SPARES BY 1
        ACT,,XX(24).LT.0,I03;            NOT ENOUGH SPARES.
;                                        MICAP
        ACT,,XX(24).GE.0,J03;            ENOUGH SPARES?
;
I03     GOON;
        ASSIGN,XX(22)=XX(22)-1;          DECREMENT # OF A/C
        AWAIT(13),DMT3/1,BLOCK,1;
        ACT;
;
J03     GOON,2;
        ACT,,,L03;
        ACT,,,K03;
;
K03     GOON,1;
        ASSIGN,ATRIB(1)=0.0;
        ASSIGN,ATRIB(2)=EXPON(XX(28));
        ACT,,,F03;
;
L03     QUEUE(3);
        ACTIVITY(1)/29,2;                      2 HR TST 03
        GOON;
        ACTIVITY/26,,ATRIB(4).NE.1.0,M03;      DIAGNOSE 03
        ACTIVITY/27,,ATRIB(4).EQ.1.0,S03;      POST RPR 03
;
M03     GOON;                                  DIAGNOSED
        ACTIVITY,0,XX(42),P03;                 NRTS RATE
        ACTIVITY,0,XX(44),S03;                 BCS RATE
        ACTIVITY,2,XX(43),N03;                 RTS RATE
;
N03     GOON;
        ACTIVITY;
        ASSIGN,ATRIB(4)=1.0;
        ACTIVITY,,,L03;
;
P03     GOON;                           NRTS TO DEPOT
```

```
      ACTIV.TY/28,1056,,DEPO;           TO DEPOT 03
;                                       44 DAYS
;
;
; ==========================================================
;
S03   GOON;                          BASE 03 (TAC/AFSC) SUPPLY
      ASSIGN,XX(24)=XX(24)+1;
;      COLCT,XX(24),# SPARES 03,50/-190/8;
;
      GOON;
      ACT,,XX(24).GT.0,U03;
      ACT,,XX(24).LE.0,T03;
;
T03   GOON;
      ASS,XX(22)=XX(22)+1;
      FREE,DMT3/1;
      ACT;
;
U03   GOON;
;      COLCT,XX(22),# AV_AC 03,50/0/4;
      TERM;
;
;  ****************************************************
;   ATC/AFRES
;  ****************************************************
;
;    THIS FIRST SECTION CREATES THE AIRCRAFT WITH VARYING
;    AMOUNTS OF FLIGHT TIME SINCE LAST FAILURE OF A DMT.
;
C04   CREATE,0,,,82;              CREATE AIRCRAFT
      ACT/31;                     # AC 04
;
      ASSIGN,ATRIB(2)=EXPON(XX(38));        MTBF
      ASSIGN,ATRIB(1)=UNFRM(0,ATRIB(2));  INIT TIME ON A/C
      ASSIGN,XX(31)=ATRIB(1);
;
;   THE A/C ARE NOW CREATED AND READY TO FLY AND TO FAIL.
;   =====================================================
;
F04   GOON;
      ACTIVITY;
      ASSIGN,ATRIB(3)=RNORM(XX(41),.2);   SORTIE LENGTH
      ASSIGN,ATRIB(1)=ATRIB(1)+ATRIB(3);  FLT HRS SINCE
;                                         FAILURE
;
G04   GOON;
      ACT/33,ATRIB(3);                  SORTIES 04
      ASSIGN,ATRIB(4)=0.0;
      GOON;
      ACTIVITY/54,XX(36);               WAIT, ATC/AFRES
```

```
;
        GOON;
        ACT/34,,ATRIB(1).GT.ATRIB(2),H04; DMT FAIL 04
        ACT/35,,ATRIB(1).LE.ATRIB(2),F04; DMT GOOD 04
;
H04     GOON;
        ASSIGN,XX(33)=ATRIB(1);           MTBF
        ASSIGN,XX(34)=XX(34)-1;           DECREMENT SPARES BY 1
        ACT,,XX(34).LT.0,I04;             NOT ENOUGH SPARES.
;                                         MICAP
        ACT,,XX(34).GE.0,J04;             ENOUGH SPARES?
;
I04     GOON;
        ASSIGN,XX(32)=XX(32)-1;           DECREMENT # OF A/C
        AWAIT(14),DMT4/1,BLOCK,1;
        ACT;
;
J04     GOON,2;
        ACT,,,L04;
        ACT,,,K04;
;
K04     GOON,1;
        ASSIGN,ATRIB(1)=0.0;
        ASSIGN,ATRIB(2)=EXPON(XX(38));
        ACT,,,F04;
;
L04     QUEUE(4);
        ACTIVITY(1)/39,2;                         2 HR TST 04
        GOON;
        ACTIVITY/36,,ATRIB(4).NE.1.0,M04;         DIAGNOSE 04
        ACTIVITY/37,,ATRIB(4).EQ.1.0,S04;         POST RPR 04
;
M04     GOON;                                     DIAGNOSED
        ACTIVITY,0,XX(42),P04;                    NRTS RATE
        ACTIVITY,0,XX(44),S04;                    BCS RATE
        ACTIVITY,2,XX(43),N04;                    RTS RATE
;
N04     GOON;
        ACTIVITY;
        ASSIGN,ATRIB(4)=1.0;
        ACTIVITY,,,L04;
;
P04     GOON;                           NRTS TO DEPOT
        ACTIVITY/38,1056,,DEPO;         TO DEPOT 04
;                                       44 DAYS
;
;   ========================================================
;
S04     GOON;                          BASE 04 (ATC/AFRES) SUPPLY
        ASSIGN,XX(34)=XX(34)+1;
```

```
;       COLCT,XX(34),# SPARES 04,45/-90/4;
;
        GOON;
        ACT,,XX(34).GT.0,U04;
        ACT,,XX(34).LE.0,T04;
;
T04     GOON;
        ASS,XX(32)=XX(32)+1;
        FREE,DMT4/1;
        ACT;
;
U04     GOON;
;       COLCT,XX(32),# AV_AC 04,50/0/2;
        TERM;
;
;   *****************************************************
;       DEPOT
;   *****************************************************
;
DEPO    QUEUE(5);                          DEPOT RPR
        ACT(25)/10,240;                    10 DAYS
        ASSIGN,XX(7)=USERF(1);
;       COLCT,XX(7),USERF,4/0/1;
        GOON,1;
        ACT,1248;                          52 DAYS BACK TO BASE
        GOON,1;
        ACT/41,,XX(7).EQ.1,S01;            TO PACAF
        ACT/42,,XX(7).EQ.2,S02;            TO USAFE
        ACT/43,,XX(7).EQ.3,S03;            TO TAC/AFSC
        ACT/44,,,S04;                      TO ATC/AFRES
;
;
;   *****************************************************
        ENDNETWORK;
;   *****************************************************
;
;   RECORD,TNOW,#SPARES ALL,,B,200;
;   VAR,XX(4),S;                       NUMBER OF ADDITIONAL
;   VAR,XX(14),T;                      SPARES
;   VAR,XX(24),U;
;   VAR,XX(34),V;
;   RECORD,TNOW,DEPOQ,,B,200;
;   VAR,NNQ(5),D;
INITIALIZE,0,24380;                    1/2 YR PLUS WARM-UP
MONTR,CLEAR,20000;                     WARM-UP (APPROX 2.3
YEARS)
FIN;
```

```
C
C                    Fortran subroutines
C
      PROGRAM MAIN
      DIMENSION NSET(300000)
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(MATRB),DD(MEQT),DDL(MEQT),
     1DTNOW, II,MFA,MSTOP,NCLNR, NCRDR, NPRNT, NNRUN, NNSET,
     2NTAPE,SS(MEQT),SSL(MEQT),TNEXT, TNOW, XX(MMXXV)
      COMMON QSET(300000)
      EQUIVALENCE (NSET(1),QSET(1))
      NNSET=300000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      CALL SLAM
      STOP
      END
C
      FUNCTION USERF(N)
      INCLUDE 'SLAM$DIR:PARAM.INC'
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,
     1MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),
     2SSL(100),TNEXT,TNOW,XX(100)
C
      GO TO (1,2),N
 1    IF ((XX(4)/XX(2)).LT.(XX(14)/XX(12))) GO TO 20
      X5=(XX(14)/XX(12))
      I1=2
      GO TO 30
 20   X5=(XX(4)/XX(2))
      I1=1
 30   IF ((XX(24)/XX(22)).LT.(XX(34)/XX(32))) GO TO 40
      X6=(XX(34)/XX(32))
      I2=4
      GO TO 50
 40   X6=(XX(24)/XX(22))
      I2=3
 50   IF (X5.LT.X6) GOTO 60
      USERF=I2
      GO TO 70
 60   USERF=I1
 70   RETURN
      END
C
      SUBROUTINE EVENT(I)
      CALL CLEAR
      RETURN
      END
```

Appendix B. Sample Output

S L A M   I I   S U M M A R Y   R E P O R T

SIMULATION PROJECT A1 BY ROB SHELL

DATE 7/15/1989 RUN NUMBER 1 OF 30

CURRENT TIME 0.2438E+05
STATISTICAL ARRAYS CLEARED AT TIME 0.2000E+05

STATISTICS FOR TIME-PERSISTENT VARIABLES

	MEAN VALUE	STD DEV	MIN VALUE	MAX VALUE	TIME INTERVAL	CURRENT VALUE
# SPARES 01	82.744	2.659	76.00	88.00	4380.00	79.00
# SPARES 02	161.205	4.399	152.00	172.00	4380.00	156.00
# SPARES 03	124.359	3.807	112.00	130.00	4380.00	120.00
# SPARES 04	56.292	1.679	51.00	61.00	4380.00	54.00

FILE STATISTICS

FILE NUMBER	LABEL/TYPE	AVERAGE LENGTH	STANDARD DEVIATION	MAXIMUM LENGTH	CURRENT LENGTH	AVG WAIT TIME
1	L01 QUEUE	0.009	0.099	2	0	0.303
2	L02 QUEUE	0.022	0.170	3	0	0.422
3	L03 QUEUE	0.024	0.205	4	0	0.611
4	L04 QUEUE	0.001	0.034	1	0	0.148
5	DEPO QUEUE	0.531	1.404	10	0	6.052
6		0.000	0.000	0	0	0.000
7		0.000	0.000	0	0	0.000
8		0.000	0.000	0	0	0.000
9		0.000	0.000	0	0	0.000
10		0.000	0.000	0	0	0.000
11	AWAIT	0.000	0.000	0	0	0.000
12	AWAIT	0.000	0.000	0	0	0.000
13	AWAIT	0.000	0.000	0	0	0.000
14	AWAIT	0.000	0.000	0	0	0.000
15	CALENDAR	861.751	10.025	888	878	19.331

REGULAR ACTIVITY STATISTICS

ACTIVITY INDEX/LABEL	AVG UTIL	STD DEV	MAXIMUM UTIL	CURRENT UTIL	ENTITY COUNT
1 # AC 01	0.0000	0.0000	0	0	0
3 SORTIES 01	3.0802	6.5537	34	0	7938
4 DMT FAIL 01	0.0000	0.0000	1	0	116
5 DMT GOOD 01	0.0000	0.0000	1	0	7821
6 DIAGNOSE 01	0.0000	0.0000	1	0	116
7 POST RPR 01	0.0000	0.0000	1	0	19
8 TO DEPOT 01	20.3041	4.9544	30	18	83
11 # AC 02	0.0000	0.0000	0	0	0
13 SORTIES 02	7.8595	13.4193	53	0	20273
14 DMT FAIL 02	0.0000	0.0000	1	0	196
15 DMT GOOD 02	0.0000	0.0000	1	0	20036
16 DIAGNOSE 02	0.0000	0.0000	1	0	197
17 POST RPR 02	0.0000	0.0000	1	0	29
18 TO DEPOT 02	37.5904	5.4172	49	28	164
21 # AC 03	0.0000	0.0000	0	0	0
23 SORTIES 03	5.4609	9.7276	44	1	14073
24 DMT FAIL 03	0.0000	0.0000	1	0	157
25 DMT GOOD 03	0.0000	0.0000	1	0	13909
26 DIAGNOSE 03	0.0000	0.0000	1	0	157
27 POST RPR 03	0.0000	0.0000	1	0	16
28 TO DEPOT 03	27.2691	6.1710	40	38	111
31 # AC 04	0.0000	0.0000	0	0	0
33 SORTIES 04	1.8813	4.3392	25	0	4838
34 DMT FAIL 04	0.0000	0.0000	1	0	34
35 DMT GOOD 04	0.0000	0.0000	1	0	4804
36 DIAGNOSE 04	0.0000	0.0000	1	0	34
37 POST RPR 04	0.0000	0.0000	1	0	1
38 TO DEPOT 04	6.3780	2.1887	10	6	26
41 TO PACAF	0.0000	0.0000	1	0	84
42 TO USAFE	0.0000	0.0000	1	0	140
43 TO TAC/AFSC	0.0000	0.0000	1	0	116
44 TO MCD/AFRES	0.0000	0.0000	1	0	20
51 WAIT,PACAF	122.9124	6.5507	126	126	7937
52 WAIT,USAFE	238.1409	13.4193	246	246	20232
53 WAIT,TAC/AFSC	184.5385	9.7276	190	189	14066
54 WAIT,MCD/AFRES	80.1188	4.3392	82	82	4838

SERVICE ACTIVITY STATISTICS

ACT NUM	ACT LABEL	SER CAP	AVG UTIL	STD DEV	CUR UTIL	AVG BLOCK	MAX IDL TME/SER	MAX BSY TME/SER	ENT CNT
9	TST 01	1	0.062	0.24	0	0.00	203.61	10.00	135
19	TST 02	1	0.103	0.30	0	0.00	101.63	12.00	226
29	TST 03	1	0.079	0.27	0	0.00	173.10	18.00	173
39	TST 04	1	0.016	0.13	0	0.00	440.18	4.00	35
10	10 DAYS	25	21.063	3.51	22	0.00	12.00	25.00	386

Appendix C. Analysis of Variance

Null Hypothesis : the means are equal
Alternate Hypothesis: the means are not equal

Test Statistic: $F = s_B^2 / s_W^2$

= variance between samples / variance within samples

$\alpha = 0.10$
$df_1 = t - 1$ = (# population means) - 1
$df_2 = n - t$ = (total # of observations) - (# population means)

Reject the null hypothesis if an F value in any case (S, T, U, or V) is greater than F^*, the tabled value.

Case 1: 2 batches of 4 years each

	F^*	S	T	U	V
$\alpha = 0.10$					
$df_1 = 1$	2.88	0.11	0.01	0.14	0.05
$df_2 = 30$					

Case 2: 4 batches of 2 years each

	F^*	S	T	U	V
$\alpha = 0.10$					
$df_1 = 3$	2.29	1.22	1.11	1.37	0.91
$df_2 = 28$					

Case 3: 8 batches of 1 year each

	F^*	S	T	U	V
$\alpha = 0.10$					
$df_1 = 7$	1.98	0.84	1.01	0.98	0.91
$df_2 = 24$					

Case 4: 16 batches of 1/2 year each

	F^*	S	T	U	V
$\alpha = 0.10$					
$df_1 = 15$	1.94	0.72	0.82	0.81	0.87
$df_2 = 16$					

For all cases the ANOVA shows an inability to reject the null hypothesis that the means are equal; propose a run length of one-half year plus 20,000 hour warm-up period.

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This thesis provides a methodology for the analysis and comparison of various maintenance practices for the F-16C/D Dual Mode Transmitter. The primary goal of this thesis is the determination of whether a reduction from three to two levels of maintenance is viable. The measure of effectiveness selected to compare each maintenance alternative is the number of available spares corresponding to that level of maintenance. Computer simulation is the chosen method to determine this availability.

A SLAM II simulation model was developed to model the failure of the Dual Mode Transmitter and its repair at all three levels of maintenance. The validated model was then subjected to various sensitivity analyses to see which areas were most sensitive. A final analysis was done to compare three versus two levels of maintenance for peacetime flying requirements, for a 30 day wartime flying surge, and for a sustained conflict.